STATE

GEOLOGICAL SURVEY

OF

NORTH DAKOTA

THIRD BIENNIAL REPORT

A. G. LEONARD, PH. D., STATE GEOLOGIST

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UNIVERSITY OF IOWA,
IOWA CITY, May 6, 1904.

To the Trustees of the State University of North Dakota:

GENTLEMEN: I submit herewith the results of field work carried out under my direction during the summer of 1903. In accordance with the purpose stated in my report to you in 1901, the geological work undertaken by the Survey has been practical in its nature, aiming to bring out the undeveloped natural resources of the state. Co-operating with the United States Geological Survey, the possibility of irrigating considerable tracts along the Missouri and its tributaries with pumping engines which use lignite as fuel has been carefully studied with results that seem most encouraging. A report with recommendations was submitted to the hydrographic branch of the United States Geological Survey, portions of which will appear in the Second Annual Report of the Reclamation Service.

Mr. L. H. Wood, of the University of Chicago, continued to serve as assistant geologist. Messrs. Hinds, Holgate, Goodall and Pease, students of the University, served efficiently as field assistants. Mr. Wood with two assistants started at Medora and descended the Little Missouri to its mouth. Meeting my party, which had come down the Missouri in a small boat from the Montana line, a conference was held at Mannhaven. Here Mr. Woods' party fitted out by wagon for a trip up the Knife river, while my party continued its studies down the Missouri to the mouth of the Cannon Ball. From this point the valley of the Cannon Ball was followed by wagon to Wade. Here the river forks, and the party chose to follow the Cedar or South Fork of the Cannon Ball to the end of the Standing Rock Indian Reservation. Returning, observations were made along the Upper Heart river. Separate reports of the work of the two parties are submitted herewith.

At the end of the summer of 1903 I was obliged to resign the position of State Geologist of North Dakota, on account of re-

moval from the state. Dr. A. G. Leonard, whom you have chosen as my successor, enjoys the confidence of geologists throughout the country, and to his care future geological studies in North Dakota may safely be entrusted.

Respectfully submitted,

FRANK A. WILDER.

UNIVERSITY OF NORTH DAKOTA,
GRAND FORKS, October 8, 1904.

Hon. George E. Towle, President Board of Trustees of the University of North Dakota:

DEAR SIR: I have the honor to submit herewith the following report on the work of the State Geological Survey of North Dakota during the past two years. During the first half of this period the Survey was under the direction of Dr. Frank A. Wilder, whose report on the field work for the summer of 1903 is appended.

During the past year the second edition of the Second Biennial Report, dealing with the lignite deposits of the state, was issued. The demand for the report was so great that the first edition of 1,500 copies was exhausted within a few months and the Legislature authorized a second of 2,500 copies.

The frequent requests for the reports of the Geological Survey come not only from within the state but from individuals and companies all over the country. They indicate a widespread interest in the natural resources of North Dakota, and it is an important function of the Survey to furnish information concerning these resources. The answering of the numerous letters of inquiry which come to the office takes no small share of the time of the State Geologist.

The policy of the Survey in the future, as it has been in the past, will be to emphasize the economic problems presented for investigation and to do everything in its power to develop the natural resources of the state. This should in fact be the chief aim of any geological survey. In carrying out this purpose the Survey has issued a report on the topography, geology and natural resources of North Dakota; a second dealing largely with the lignite coal fields of the region, and the forthcoming Third Biennial Report will contain the results of extended investiga-

tions as to the possibility of irrigating large tracts along the Missouri and its tributaries with pumping engines, using lignite as fuel.

The summer's work of the State Geologist was directed in part toward becoming familiar with the different geological formations which occur within the state. For this purpose I visited a large number of widely separated localities where these formations appear at the surface, and the character of the rocks was carefully studied. At the same time I began the investigation of the clays, which will form the subject of the report to follow the one now in press. These have already been studied by Professor Babcock and a large amount of valuable information secured, but much is left to be done before a full report on them is published. The many excellent clays which are found in all portions of the state were examined. Detailed sections were made showing the alternation and succession of the beds, with their thickness, and these will form the basis necessary for future study. Nearly all the clay plants were visited and much valuable information concerning them secured. The brick yards and coal mines in the vicinity of Williston, Minot, Burlington and Kenmare were visited. The Laramie beds, which are so rich in seams of lignite and valuable clay deposits, were carefully studied near Medora, Sentinel Butte, Dickinson, Coal Harbor and many other points in the western part of the state. The high grade fire clays, pottery clays and brick clays at Dickinson were found to have quite a wide distribution. They outcrop in the vicinity of Gladstone and extend east of there for a considerable distance, while they are found at least several miles to the north and south of Dickinson. It is hoped that next summer sufficient work can be done on these white, high grade clays to determine their distribution, thickness and stratigraphic relationships. Other clays of good quality were observed near Jamestown and Valley City, where the Pierre shales outcrop along the James and Sheyenne rivers.

The value and possibilities of our clays are strikingly shown in the North Dakota exhibit in the Mines Building at the St. Louis World's Fair, where a great variety of beautiful and artistic pottery is displayed, all manufactured experimentally in eastern factories from the clays found near Dickinson and elsewhere in the state.

Some time was spent in the Turtle Mountain region in the endeavor to find whether lignite occurs there. Coal has for years been mined near the eastern and northern edge of the mountains, in Canada, and also near Dunseith, in Rolette county. The drift deposits are so thick in this district that the underlying coal-bearing beds of the Laramie formation do not outcrop, but good-sized fragments of the coal are found imbedded in the drift clays near Bottineau and elsewhere in the mountains, and furnish evidence that beds of coal are not far distant. It is very probable that seams of lignite will be found at no great depth below the surface, and the expense of putting down some prospect holes to determine their depth and extent would not be great, and would be warranted by the benefits secured if coal were discovered in this vicinity.

In connection with other lines of investigation, the building stones received some attention. Those near Velva, Sentinel Butte, Dickinson and elsewhere were examined and found to have the necessary durability and to be readily quarried. These sandstones form beds extensive enough to furnish an abundance of building stone of good quality. Three or four buildings in Velva have been constructed of the rock. At present about the only building stone throughout a large part of the state is supplied by the granite and other boulders of the drift, brought in from the north by the great glaciers which once covered this region.

A trip was made to the Pembina Mountains for the purpose of studying the rare and valuable cement rock and brick clays of that area.

The Third Biennial Report, which is now in the hands of the printer, contains reports on the following subjects:

(1) The Lignite on the Missouri, Heart and Cannon Ball Rivers and Its Relation to Irrigation.

(2) Report on the Region Between the Northern Pacific Railroad and Missouri River. Its Topography, Climate, Vegetation, Irrigation Possibilities and Coal Deposits.

(3) The Results of Stream Measurements in North Dakota During the Past Two Years.

(4) The Geological Formations of North Dakota.

It is believed that the volume contains much information of a very practical nature on the lignite deposits and irrigation problems, and will serve to interest and educate the citizens of

the state in the needs and possibilities of irrigation in the western portion. The maps accompanying the report show the location and thickness of the lignite seams outcropping along the chief streams, the location of the larger river flats and other interesting features of the country.

The earliest investigations in the state on the possibility of using lignite for fuel in pumping the waters of the streams up onto the adjoining river flats were carried on by the State Geological Survey under the direction of Dr. F. A. Wilder. Work on this problem was begun in the summer of 1902 and continued during the next season by two parties who followed the Missouri and its tributaries. It is gratifying to be able to report that this line of investigation has now been taken up by the reclamation division of the United States Geological Survey. The Federal Survey now has two surveying parties at work along the Missouri, one in the vicinity of Bismarck and another below Williston, studying the river flats and the possibility of irrigating them by pumping from the stream, using the lignite close by for fuel. If a favorable location can be found, the Government may establish an experimental pumping plant.

Through Professor Chandler the State Geological Survey is co-operating with the United States Geological Survey in measuring the flow of all the principal streams of North Dakota, and the results of these measurements are given in the present volume. They will be found of much value in the investigation of the irrigation possibilities of the different drainage areas.

It is greatly to be hoped that the appropriation at the disposal of the Survey during the next two years will be sufficient to make it possible to co-operate with the United States Geological Survey in the preparation of topographic maps of areas in the state. Such maps would be of the greatest service in the study of irrigation problems, and a good topographic map is necessary before geological mapping can be undertaken. As soon as the required topographic sheets have been completed the Survey will begin mapping the formations of economic importance in the western part of the state, in co-operation with the Federal Survey.

The Survey has already made considerable progress in its investigations of the valuable clay deposits of the state, and this work is being pushed to completion as fast as possible. The results will be embodied in the next report, which will contain a

full discussion of the chemical and physical properties of clays, the manufacture of the various clay products, and the geological character and distribution of the North Dakota clays. The Survey also plans to take up the study of building stone, cement rock and other subjects, and to continue the investigation of the lignite deposits, upon which there is still much to be done. Certain restricted areas, such as single counties, will be selected for careful study and detailed mapping, reports being prepared on the topography, geology and economic resources of the areas, including their water supply and irrigation problems.

The Survey is building up a valuable library through the exchanges received in return for its reports. Many volumes of reports from the Federal and State Geological Surveys are received, and also the publications of American and foreign scientific societies. The best mining and geological journals are also received in exchange.

Respectfully submitted,
A. G. LEONARD,
State Geologist.

THE LIGNITE ON THE MISSOURI, HEART AND CANNON BALL RIVERS AND ITS RELATION TO IRRIGATION

BY FRANK A. WILDER

INTRODUCTION

Opportunities to irrigate in a large way in North Dakota, for the present at least, seem to be confined to the broad terraces, or benches as they are locally called, along the Missouri and its tributaries. These streams are deeply intrenched and it does not seem possible, by any means now available, to raise water from them over the bluffs that rather sharply bound the broad valleys, a vertical distance of from 150 to 400 feet, and irrigate the upland.

Where the Yellowstone enters the state, it has a fall of only 2.7 feet per mile, while the Missouri's gradient for an equal distance is about two feet. A fall of a foot per mile is necessary to carry water in an irrigating ditch, so that to raise water forty feet from the Missouri would require a ditch forty miles long. The tributaries of the Missouri have gradients somewhat higher, but the flats along them are cut up by the meanderings of the streams, and conditions are not favorable for long lateral ditches or extensive reservoirs.

In view of the fertile terraces in the valleys of the streams themselves ranging in elevation from fifteen to 100 feet and the abundance of lignite along them, it seemed desirable to consider the possibility of irrigating the 250,000 or more acres included in the stream terraces, by pumping from the streams directly, using lignite as fuel. Co-operating with the Department of Hydrography of the United States Geological Survey, therefore, the lignite area has been studied, and practical tests have been made to determine the value of the lignite as fuel in generating steam. With these determinations as a basis computations have been made to determine, at least in a rough way, the cost of irrigating river flats whose elevation is less than 100 feet.

While engaged in these practical studies, opportunity was given to consider a number of important scientific questions, and

brief notes covering the points noted, are given in the closing paragraphs of the accompanying reports.

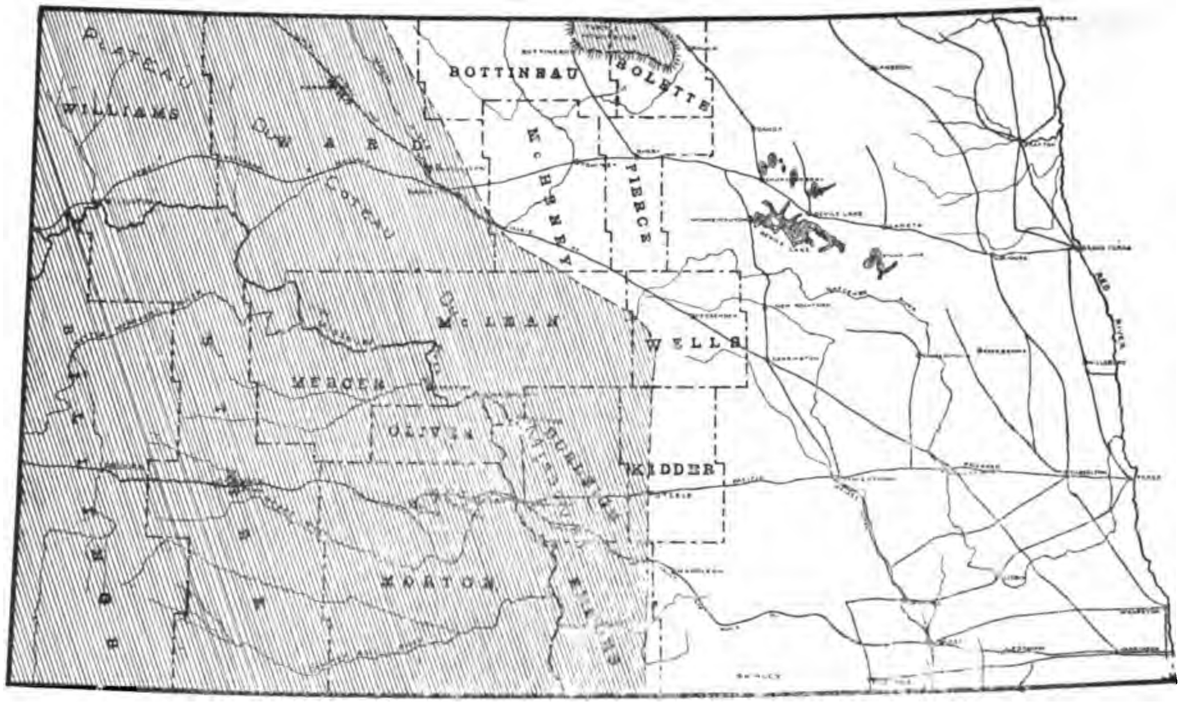
The brief statement of the facts in regard to the nature and extent of the lignite given below is taken from the more extended report of two years ago.*

EXTENT OF THE LIGNITE AREA IN NORTH DAKOTA

While thin beds of lignite have been recognized in the eastern part of the state and have been described† at the southern bend of the Sheyenne river, in Township 135, Range 54, Section 32, which lies about twenty-five miles southeast of Valley City, workable seams have not been found, except in the Turtle mountains, till the center of the state is reached. The plateau known as the Turtle mountains is an outlier of the lignite area proper, which may be roughly bounded on the east by a line beginning at the northern boundry of the state, and thirty miles east of the Minneapolis, St. Paul & Sault Ste. Marie railroad, and extending southeast to Harvey, thence south through Steele to the southern boundary. This line is shown in plate 1. More minute study, aided by well borings which will doubtless be made as the country is settled, will probably shift this line east or west at certain points thirty or forty miles. The state lines are its boundaries on the north, south and west, while outside the state the lignite continues in these three directions. Only this region, in which workable beds of lignite may reasonably be looked for, is included in this report under the term "lignite area." Even when so restricted it is of very great extent, equal to at least half of the state of Ohio.

It is highly probable that lignite does not exist in beds of workable thickness in every part of this region, but it is equally probable that the fraction of the area lacking lignite in beds of three or more feet in thickness is a small one, not more than one-fifth of the whole. In the southeastern portion of the area, about the lower part of the Cannon Ball river, thick beds seem to be lacking. Where heavy beds are present, all may not be available, either on account of depth or some difficulty in mining, and throughout the eastern portion of the region they are so thoroughly concealed by glacial drift that, without a knowledge of the underlying formations and of the surrounding country, their existence would be unsuspected.

*Second Biennial Report of the North Dakota Geological Survey.
†Upham in Monograph XXV, page 92, United States Geological Survey.



LEGEND ⚒ LOCALITIES WHERE COAL IS MINED FOR SHIPMENT

A map showing approximately the area in which lignite occurs in quantities sufficient to be of economic importance. The lignite area is marked by diagonal lines.

STRATIGRAPHY

General Relationships of Strata.—The restriction of the term "lignite area" to the area in which workable beds of lignite are found, greatly simplifies the stratigraphic series and limits this paragraph to a consideration of the Laramie and the glacial drift.

The Laramie.—This, the latest stage of the Cretaceous, contains all of the workable lignite in North Dakota. Early students of the field referred part of the lignite beds to the Fort Union on paleontological grounds. Reasons for retaining the distinction have not seemed adequate and the effort may well be dropped. The Laramie is found over the region previously outlined as the lignite area, though its eastern border is buried, often deeply, by glacial drift. The difference in elevation of deposits of this stage, actually exposed within the state, is at least 1,400 feet. Its greatest thickness, safely shown by the well at Medora to be more than 2,000 feet, occurs in the western part of the state, its vertical extent gradually decreasing toward the east, till at the edge of the Coteau du Missouri it drops off sharply, beyond which it continues as a relatively thin series. The Laramie formations consist of clays, sands, sandstone, lignite, and thin bands of hematite, clay-ironstone and shaly limestone.

Nature of the Lignite Beds.—The numerous natural exposures of lignite in the driftless area, and the remarkably fine opportunities to study the Laramie strata given by the Bad Lands, make it possible to draw, even from a preliminary study of the region, rather far reaching conclusions in regard to the nature of the lignite beds.

Number of Beds in Single Vertical Sections.—Five well developed beds outcrop in the bluffs of the Little Missouri at Medora, and may be traced for miles both north and south of this point. Along the Missouri south of Williston five and six beds show in a single section, and can be traced for long distances, while on the Fort Berthold reservation nine well developed beds occur in a single exposure. The wells at Medora and Dickinson show an even greater number of beds. Near the eastern edge of the lignite area the number of beds is greatly reduced, but even here two and three exist at certain points, though generally but one is workable.

On account of the nature of the beds, considered in a later paragraph, their number does not remain constant through large areas, and it is possible, though hardly probable, that in a few localities in the heart of the lignite area a prospect hole passing completely through the Laramie would not encounter a single lignite bed. This variation in number and thickness of seams, often within comparatively short distances, will be a factor of great practical importance in opening up on a large scale a new lignite field. In the first place, it will increase the number of prospect holes that must be sunk to determine the amount of available coal in a given area. To offset this, however, are a number of conditions which make prospecting unusually easy.

Thickness of the Beds.—The lignite beds in North Dakota vary in thickness from an inch to forty feet. This maximum thickness, which was carefully measured in the summer of 1902, outcrops in Township 135, Range 101, Section 31, and will be described in connection with the lignite on the Little Missouri river. Three beds which reach a thickness of twenty-five feet are known, while beds fifteen feet thick are not uncommon. In the western part of the state beds two and three feet thick are so common that in this report it is not practical to note them minutely.

Extent of Beds.—As important from an economic point of view as their thickness is their persistence laterally. Attention was directed to this point, and the elevation of beds was noted in order to correlate if possible the beds exposed at one point with those at another. Generally such a correlation was impossible for points distant from each other a number of miles on account of variations in thickness and elevation. While a single bed was often traced for five or six miles along the banks of the Little Missouri, others seen at the same time thinned out and gave place to others above or below them. The interrupted bed might begin again farther on after a break of half a mile or more, the lignite in the interim being replaced by a bituminous or nearly pure clay. The deduction, which early in the work seemed true, that certain horizons in the Laramie are much richer in lignite than others, was not borne out by later observations. For a given locality the statement holds good, but an elevation which abounds in lignite at one point may be barren in another. A striking instance of the rapid thinning of a bed is given by the forty-foot bed already referred to, which within

one-fourth of a mile shrinks to seventeen feet, the top and bottom drawing together like the surfaces of a lens. Sufficient work has been done at one point near Minot to demonstrate the persistence of a thick bed beneath the greater part of a township, but this seems to be the exception rather than the rule. Darton attempted to correlate the beds encountered in the wells at Medora and Dickinson, the distance between the points being thirty-nine miles, but in view of the data gathered for this report the attempt seems hardly practical.

Variations in Fuel Value of Lignite in a Given Bed.—A majority of the beds examined and tested show no great difference in fuel value from top to bottom. In some instances, however, the differences in the composition of the lignite in a given bed was considerable. Not infrequently the upper foot or two are inferior, and are left for roof in mining. The loss in this case is not as great as might be expected, for it is often more economical to leave coal for a roof than to timber. When the lignite lies directly under the glacial drift, as at the Hanchett mine ten miles southwest of Velva, the upper portion shows deterioration. Shaly layers sometimes occur, which if mixed with the coal from the rest of the bed, bring up the percentage of ash for the whole very considerably. Sulphur in any form is present commonly only in traces. Iron nodules, which prove so annoying to the operator of mining machines in the east, do not occur in the lignite, and there are no hindrances to the use of drills and undercutting machinery.

Variations in Fuel Value of Different Beds.—The chemical analyses of seventy samples from as many beds, given in a later chapter, throw light on the fuel value of lignites from as many parts of the state. Samples were not taken from beds that were obviously too thin or to impure to be of economic value, but on the other hand, all analyses made are given, whether favorable to the lignite or not. The lignites taken as a whole will probably average better than the samples analized indicate, for in many cases fresh material could not be obtained and the weathering on the surface of a natural exposure is sufficient to lessen the carbon values for some feet from the surface. In the discussion which follows lignites which are reported as good have not more than 8 per cent of ash and fixed carbon between 40 per cent and 50 per cent.

Possibilities of Bituminous Coal Existing at Greater Depths.—There are no theoretical considerations to support the rather common notion that at greater depths a higher grade of coal exists. The analyses of the coals found by the railroads in the deep drillings undertaken in the western part of the state have not been examined. But this work was done some years ago, and since no development work has followed it the inference seems fair that bituminous coal in significant quantities was not found.

A Popular Fallacy in Connection with the Lignite.—The belief so often expressed, that lignite beds outcropping on erosion slopes are certain to thicken as the mine goes back into the hill, is hard to account for except in the optimism which fortunately is an endowment of a large part of our race. While in many cases the beds doubtless thicken away from the outcrop, the reverse will as often prove true. The lignite beds being in general lens-like, it is impossible without drilling to determine whether the outcrop represents a section near the edge of the lens or across the center. In the former case the lignite will thicken as the drift goes into the hill or bank till the center of the lens is reached, while in the latter it will become thinner.

Summary of Boiler Tests.—Careful evaporative tests with North Dakota lignite have been made, which are given at length elsewhere.* These experiments, undertaken at the Asylum for Insane at Jamestown, Missouri Valley Milling Co. at Mandan, Fargo Edison Electric Co. at Fargo, the State University at Grand Forks and the State Agricultural College at Fargo, plainly show that a pound of lignite will evaporate 4.1 pounds of water under ordinary boilers. With these figures as a basis, it is possible to determine the economy resulting from the use of lignite when competing with other fuels in any part of the state.

PUMPING WATER FOR IRRIGATION, USING LIGNITE AS FUEL

The computations here given, which indicate the amount of lignite that will be required to raise water to the level of the various flats found on the streams in western North Dakota, have been made by Charles S. Magowan, Professor of Municipal and Sanitary Engineering at the State University of Iowa. He accompanies the computations given in the table with the following statements.

*Second Biennial Report, North Dakota Geological Survey.

The first question that presents itself is that of the duty on water. In the absence of definite data on this point from North Dakota, it is necessary to rely on the results of irrigators who have worked under somewhat similar conditions. Wilson* records that in Montana about eighty acres are served per second foot of water supplied, and that if from fifteen to eighteen inches in depth be furnished during an irrigating season, it is believed to be sufficient. Mr. Wilson makes the general statement that 1,000 gallons per minute will irrigate from five to ten acres per day, and in the course of a season about 100 acres.

If water is supplied to a ten-acre tract at the rate of 1,000 gallons per minute for twenty-four hours, the depth of the water over the whole tract will be 5.58 inches. If water to this depth applied five times during the irrigating season is sufficient, a plant of this capacity should care for 200 acres.

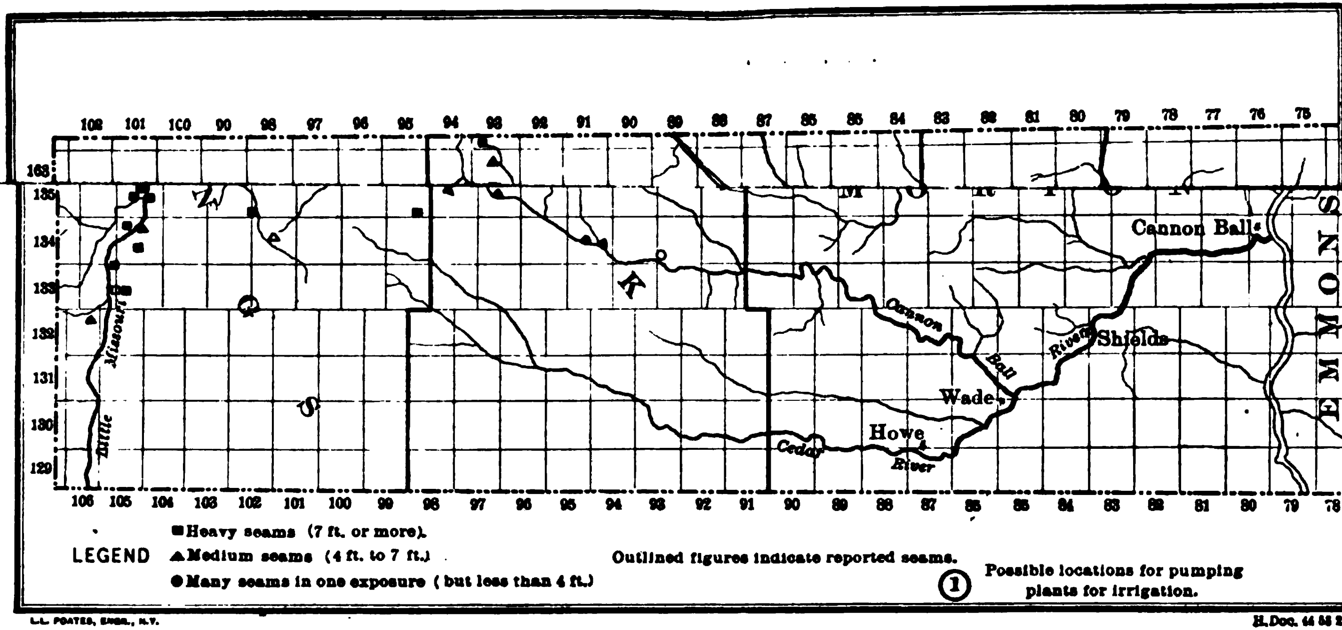
This statement is made because it is desired to use 1,000 gal-gons per minute and multiples thereof in discussing pump efficiencies.

Centrifugal pumps only are discussed, since it is believed that, in view of the recent improvements that have been made in their construction, no other pump can so economically handle large quantities of water under the given conditions, even for the higher lifts. The discussion is based on belt driven centrifugal pumps, though some reference will be made to steam centrifugal pumping engines; that is to machines where engine and pump are direct-connected, being built on the same base.

The evaporative power of the lignite is taken as 4.1 pounds of water per pound of coal as shown by test quoted elsewhere.†

*Manual of Irrigation Engineering, pages 40, 41 and 322.
†Second Biennial Report, North Dakota Geological Survey, 1901-3.

Diameter of Discharge Opening.	Capacity in Gallons per Minute.	Horse Power Delivered to Shaft Necessary to Give Economical Discharge at Elevations Named.				Efficiency of Pump—Percentage.	Amount of Lignite in Tons Required to Furnish Power to Operate the Pump Twenty-four Hours Elevating the Economical Discharge.				Price of Pump.	
		20 ft	40 ft	60 ft	80 ft		20 ft	40 ft	60 ft	80 ft		
6	1,050	11.8	23.6	35.4	47.2	45	1.2	2.4	3.6	4.8	$120	$280
8	2,000	22	44	66	88	46	2.2	4.4	6.6	8.8	190	390
10	3,000	32	84	96	128	47	3.2	6.4	9.6	12.8	240	570
15	7,000	70	140	210	280	51	7	14	21	28	400	840
18	10,000	100	200	300	400	52	10	20	30	40		900
20	12,000	120	240	360	480	53	12	24	36	48		
24	15,000	130	260	390	520	58	13	26	39	52	1,700 Volute	
36	32,000	260	520	780	1,040	62	26	52	78	104		



Outcrops of lignite examined during the summers of 1902-3. The position of the old valley, referred to in the text, and the larger flats, are indicated (the last by numbers).

RIVER FLATS AND LIGNITE ALONG THE MISSOURI

Geological work undertaken during the summer of 1902 along the Missouri river had made evident the existance of large quantities of lignite at a number of points on this stream, and of extensive flats of moderate elevation.

To determine the abundance of lignite, the amount of land included in the flats and the size of the more extensive tracts, in the summer of 1903 a party of three followed the river from the Montana line to the mouth of the Cannon Ball river. The more extensive flats studied at this time are described separately on the following pages. Smaller flats of from 100 to 500 acres were of too frequent occurence to permit of detailed examination. The larger maps of the Missouri River Commission were found most helpful, and should be secured by any one who proposes to locate one of the smaller flats on the Missouri for the purpose of irrigation and farming.

The Yellowstone Flat in North Dakota.—On entering North Dakota, the course of the Yellowstone is toward the northwest, then north, and just before uniting with the Missouri flows for nearly two miles somewhat south of west, its total course in the state amounting to about fifteen miles. For this distance it keeps close to the bluffs at the right bank of the valley, leaving broad benches unbroken by meanders on the left. Above the flood plain, which is covered with a dense growth of willows, is a wooded bench from ten to fifteen feet above high water, where large cottonwoods flourish. Its extent may equal 4,000 or 5,000 acres. Ten feet above this, and twenty feet above the river at high water is the edge of a beautiful and extensive grassed terrace which rises gradually for two miles to the foot of the bluffs, and below the contour line that might be drawn eighty feet above the river will include about 15,000 acres. It is not cut up by ravines or gullies, and a trench can be carried along the eighty foot contour with but few flumes, and water can be conveyed to almost any point on the flat if it has this initial head.

The soil is a good loam and the upper terrace is already well grassed, though at present it yields hay regularly only where naturally irrigated by water that comes down in Four and Eight mile creeks and other coulees and spreads out over its surface. Much of the woodland lies high enough above the river to be free from ordinary river floods and is inundated only at rare intervals and then on account of the gorging of the ice. In all, at

least 15,000 acres on the left bank of the Yellowstone in North Dakota may be regarded as fit for irrigation, if water from the river can be raised eighty feet.

The area in North Dakota is but part of flats that extend into Montana as far as Terry. The fall of the Yellowstone is but 2.7 feet per mile and a slope of a foot per mile would probably be needed in a lateral ditch. A very long lateral will be necessary to take the water from the Yellowstone and cover the flats, if gravity is relied on alone.

Heavy deposits of lignite occur near Sidney, Mont., fifteen miles west of the North Dakota line, and on the Yellowstone river. On the creeks which empty into the Yellowstone from the south, notably Charbaneau creek, heavy beds of lignite are said to outcrop.

The Buford-Trenton Flat.—Extending along the north side of the Missouri, from the state line to the eastern edge of the old Fort Buford reservation, a distance of sixteen miles, is an extensive flat which needs only water to become highly productive. At Trenton station, in the middle of this tract, the river swings in abruptly till it is close to the bluff and the flat is narrow here for half a mile. Enough remains, however, so that if water were available and it seemed desirable the level bench both east and west of Trenton could be irrigated from a single central station.

The flat includes some 12,000 acres, divided between an upper, grassed terrace and a lower, wooded bench, the former exceeding the latter by about two to one. The wooded bench is from twenty to twenty-five feet above ordinary high water and is said to have been flooded but twice in twenty-eight years, the last time in the spring of 1891. In places it is being cleared and cultivated. Although sandy in places, for the most part it has a good soil. The second, or grassed terrace, rises gradually from the edge of the wooded terrace, where it is about thirty feet above high water, to the bluffs at whose base it is eighty feet above the river. It has a strong gumbo soil and grows blue-joint, or wheat grass, with cactus and sage when unirrigated, while with irrigation it is abundantly productive both in grass and grain.

The vegetation on this flat when not irrigated is shown in plate 2, while plate 3 shows an adjacent tract that has been irrigated by flooding for two years. The cactus and sage brush

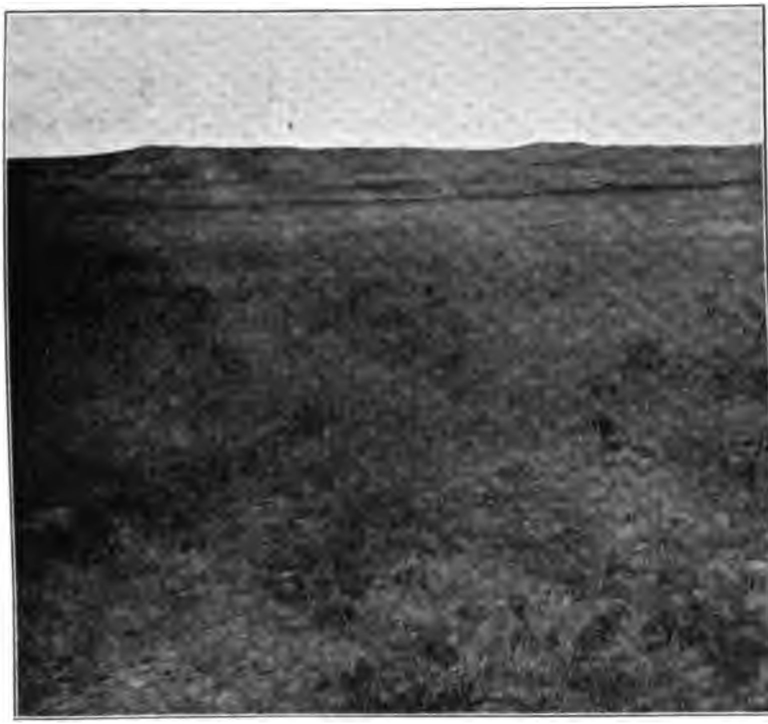


Fig. 1. Flat at Trenton, not irrigated

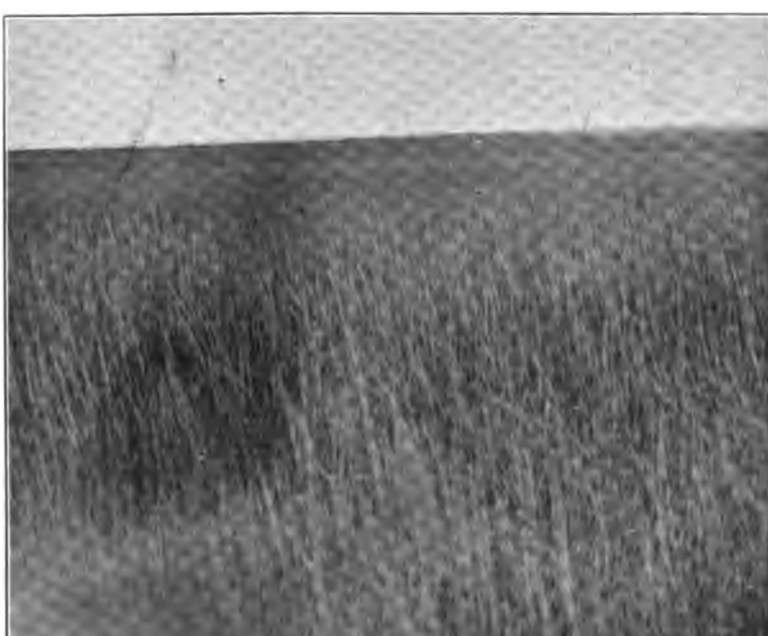


Fig. 2. The same flat under irrigation

have given place wholly to the blue grass, which grows luxuriously, yielding two and a half tons of excellent hay to the acre. The Great Northern railway crosses it, running at the foot of the bluffs, and produce raised on it will find easy access to market.

The efforts now being made by Mr. Edwin Jack and others, to irrigate parts of this area are described on another page. It will be possible to irrigate a portion of it, as they are doing, by building reservoirs and diversion dams in the draws that cut the bluffs behind the flat, but for a large portion of it the economy of this method may fairly be doubted. For the area as a whole it will be advisable to consider the possibility of raising water from the Missouri river.

Coal near the Buford-Trenton Flat.—Only limited quantities of lignite are known in the bluffs just back of this tract, though large beds may sometime be discovered. Two miles from Buford, in Township 153, Range 103, Section 31, a four-foot bed of good lignite is mined to a limited extent by stripping. About seventy-five tons were taken out in the winter of 1902.

On Eight Mile creek, above Ed Jack's ranch, a three and one-half-foot seam furnishes some lignite, while fuel from Buford is in part brought from the Yellowstone, from the seams in Glass Bluffs across the river and four miles to the southeast, the hauling being done in the winter when the river is frozen. At Glass Bluffs lignite outcrops in a number of seams, as is shown by the following section:

	FEET
Glacial drift	25
Gravel	4
Clay, seams of various colors	140
Lignite, poor	.5
Clay	4
Lignite	3
Clay	7
Lignite	3.5
Clay, yellow	35
Lignite, just below high water (reported by E. E. Jones of Buford)	4.1

When visited the lignite forming the lowest member of the section was not visible.

If a pumping station were established at Trenton, where the river cuts back nearly to the bluffs and divides the tract in question nearly in two, it might be practical to ship coal from the

mines already opened in the vicinity of Williston, a distance of only twenty-five miles. In this case good lignite f. o. b. cars at Trenton will cost $2.50, a price quoted this fall by responsible persons.

The lift at this point, to cover the entire tract of 12,000 acres, will be about seventy feet, though a large part of it could be watered with a lift considerably less.

The Little Muddy and Missouri River Flats at Williston.—The Little Muddy is the main tributary of the Missouri from the east and north in North Dakota. Its drainage area includes nearly one-half of Williams county, or 700 square miles. In addition to a water supply from direct rainfall it is fed by a number of perennial springs. On June 27, 1903, it had a flow of eighteen second feet, and this amount of water was said to be normal for that season of the year.

Its valley is broad and in the main fertile. The bottom lands often are a mile wide, while a strip half a mile wide that is fit for irrigation may be counted on for twenty miles or more from its mouth. There may be 10,000 acres along the stream that could be irrigated, if it can be shown that water can be found for so large an area.

Along its tributaries there is much land not included in the above estimate, portions of which are already irrigated, mainly by diversion dams for spring flooding.

To be taken with the Little Muddy river flats, are three or four thousand acres on the Missouri at Williston, between this town and the mouth of the Muddy. It is probable that the amount of water that the Muddy annually contributes to the Missouri is more than adequate to water the 15,000 acres that lie near it, but it has not been demonstrated that a large reservoir can be located on the stream economically. Its valley for fifteen miles is broad and offers no point where a short wall can retain any considerable amount of water. If a dam were erected above this point the water from some of the principal tributaries, which empty below, would be lost. The Fred Rounsaville dam, which was intended for a diversion dam rather than for a reservoir, has been described on another page.

There is an abundance of lignite on the Big Muddy and its tributaries, and along the Missouri below Williston. Banks that are opened up for local use about Williston and on the creeks to the north are as follows:

The Rounsaville dam on the Little Muddy above Williston

The Mackersie bank on Sand creek, in Township 154, Range 101, Section 6.

The Holland bank, close to the Muddy river and six miles north of Williston, where a heavy bed of lignite is exposed.

The Lovejoy mine on Stony creek, where considerable beds outcrop close to the Great Northern railroad.

The mine of the Pioneer Coal Company is more extensively developed than any of these and lignite is shipped from it in considerable quantities. It is located directly on the railroad, which here follows the valley of Stony creek, in Township 155, Range 100, Section 26. The bed mined is six feet thick.

The Miller mine on Cedar coulee, a tributary of the Missouri, is located four miles east of Williston. A twelve-foot bed here outcrops and will furnish a large amount of excellent coal.

A number of lignite outcrops four and six feet thick occur along Cow creek, a tributary of the Big Muddy, and are mined to some extent for local use.

The old Dahl mine, three miles southeast of Williston, was located on a four-foot outcrop in the Missouri river bluffs, on the left bank of the river.

A mile farther down the river on the right bank, in a single vertical section, eight lignite beds outcrop, the thickest being four feet.

On account of the location of the flats about Williston, their nearness to the railroad and to the town, and because most of the settlers in the Big Muddy valley are desirous of leasing water from some responsible party, a careful study of the valley is recommended.

The Nesson-Hofflund Flats.—The postoffices of Nesson and Hofflund are situated on the Missouri river, about thirty miles east of Williston and fourteen miles south of the Great Northern railroad, the nearest station being the town of Ray. Hofflund is six miles east of Nesson.

In this vicinity the Missouri receives a number of tributaries. South Tobacco Garden and Clark creeks unite with it from the south, and North Tobacco Garden, Beaver and White Earth creeks from the north.

Two extensive flats or terraces are developed here, one from twenty to forty feet above high water, extending from Nesson to Hofflund, some six miles along the river, and the other from eighty to 100 feet high and located back of Nesson. The upper

terrace includes 7,500 acres, held by more than thirty homesteaders and settlers. The lower flat includes about 6,000 acres. The soil of the upper bench is sandy loam with clay subsoil, excepting a narrow strip along the lower edge which is gravelly. The lower bench has from one to four feet of fertile, sandy loam on its surface and sand for a subsoil. A portion of the lower flat is wooded, but for the most part at this point the woodland is confined to the flood plain, which is not here considered as part of the lower terrace. A portion of the lower terrace is suffering considerably from the inroads of the river, but the loss due to this cause is not serious enough to interfere with any scheme for the development of the flat as a whole. The slope of the surface of both terraces is favorable for irrigation.

For many reasons the region invites study with reference to the possibility of irrigating it in an extensive manner. The area, especially when both terraces are considered, is considerable, the soil inviting and the distance from a railroad shipping point only fourteen miles. Heavy seams of lignite of good quality outcrop in the immediate vicinity, and a pumping station that would furnish water for the lower flat may, it is thought, be placed close to one of these outcrops and the hauling of fuel be greatly reduced or wholly obviated. On account of the lift it will hardly be practical to irrigate the upper flat with water elevated from the river, and North Tobacco Garden, Nelson and Beaver creeks may be considered as possible sources of supply.

North Tobacco Garden creek, which unites with the Missouri at Nesson postoffice, has a drainage area of twenty square miles and is fed by strong springs. Cusack springs, at the source of its west fork, in Township 154, Range 98, Section 12, are perennial and flow three second feet even in midsummer. Deer coulee heads at a spring about as strong and unites with North Tobacco Garden creek a few miles above Nesson. During the summer the creek suffers some loss of volume because of the porous nature of the stream bed at some points. On July 4, 1903, it had a flow of five second feet at its mouth, an amount somewhat less than that of its spring sources.

At least two suitable reservoir sites seem to exist on North Tobacco Garden creek, one occurring a mile back of the upper Nesson flat, where the creek emerges from the bluffs. Another site, with apparently a larger capacity, occurs five miles further up the creek. The ability of the creek to furnish water enough

The Rounsaville ditch on the Little Muddy above Williston. The width of the valley is here shown

to fill extensive reservoirs, however, has not been demonstrated. Nelson creek, which drains forty square miles, could also be used, as it is now in a measure, in irrigating the upper flat. It is spring fed, though the springs are weak and most of its available water is due to the melting of snow in the spring. On another page the tracts at present irrigated in this vicinity were noted.

Beaver creek drains 120 square miles in southeastern Williams county. On reaching the Missouri river flats it turns to the east and its bed gradually becomes ill defined, until at last it spreads its water over the nearly level surface. Six miles above its mouth, on July 8th, its flow was eighteen second feet, which was considerably more than its flow nearer the mouth. In the spring of an ordinary year its discharge is considerable. Its descent is rapid and it seems possible to utilize its waters, if they can be properly stored, to irrigate at least a part of the upper terrace.

The water from these three creeks would seem sufficient to irrigate the 7,500 acres on the upper flat, which on account of the elevation of from eighty to 100 feet, can hardly profit by any scheme to utilize the water of the Missouri river.

On these creeks boulders are fairly abundant. Aside from these and beds of soft sandstone no other stone occurs in the vicinity that could be used in reservoir construction.

For the lower flat, which includes 7,000 acres, pumping from the Missouri may be practical, for fuel is abundant, as shown by the following list of lignite outcrops that occur in this region.

At Spanish Point, on the opposite side of the river and four miles farther up, four heavy beds outcrop in the bluffs. The aneroid gave the following elevations for the beds:

Aneroid reading at top of bluff	2,850 feet
Lignite, three feet, at	2,730 feet
Lignite, six feet, good, at	2,690 feet
Lignite, fifteen feet, good, at	2,500 feet
Lignite, eight feet, good, at	2,450 feet
High water of river, about	2,400 feet

The elevations show merely the relative positions of the beds, and may vary considerably from the absolute elevations. The bluff is one of the highest in the state.

On Deer coulee, a tributary of Beaver creek, at the Marmon ranch, four miles from Nesson postoffice, a ten-foot seam of good lignite outcrops and a strong spring issues from it. A seam of

this thickness is reported at a number of points at about the same elevation as this outcrop and the bed may be regarded as rather extensive.

Along North Tobacco Garden creek two seams, six and eight feet thick, outcrop at a number of points, both seams often being exposed in the same vertical section. They can furnish great quantities of good lignite.

On Beaver creek a four-foot bed outcrops frequently and is used locally. Three miles above Hofflund a ten-foot bed is mined somewhat more extensively. An entry has been carried in thirty feet. It lies so low that in high water it is partially filled from the creek.

In the bluffs across the Missouri Mr. H. A. Carey takes coal from a six-foot seam.

Lauchland's bank, located close to the west end of the lower flat, is said to show a good bed of lignite about eight feet thick.

At Stony point, on the right bank of the river, between Nesson and Hofflund, two beds of good lignite, each three feet thick were seen, and a heavier bed is said to outcrop at this point.

The Fort Berthold Agency Flats.—The flats about the present agency on the Fort Berthold reservation, which are low enough to justify study with reference to irrigation by pumping from the Missouri, include 5,000 acres. Of this, perhaps 1,200 acres were formerly woodland which was recently burned over, leaving them practically clear while 800 acres are still covered with large trees. This woodland area is but twenty feet above high water, has a sandy loam soil and is very rarely covered by water during ice gorges. Twenty feet above this lies a well grassed flat of 1,200 acres, and still higher, perhaps eighty feet above the river, is a terrace containing some 2,000 acres.

Lignite outcrops frequently in the vicinity. Directly across the river, at high water level, three and a half feet of lignite were exposed on July 8, 1903, and the bed was reported by the superintendent of the agency to be ten feet thick. It has supplied coal for the agency during the winter, when the river is low and crossing on the ice is possible.

In the bluffs, three and one-half miles below the agency and on the same side of the river, a nine-foot bed, with a foot of clay in the middle, outcrops fifty feet above the low river flat. A half mile further south the following section is exposed:

Fig. 1. Part of the upper terrace at Nesson

Fig. 2. One of the larger flats on the Missouri river, forty feet above water level

	FEET
Lignite, six inches of clay in the middle	6
Clay	20
Lignite	2
Clay	5
Lignite	3
Clay	50
Slope to lower river flat	20

All of the lignite in this section seems to be good.

Seven miles below the Berthold agency, Mr. W. C. Dean reports a twelve-foot bed of lignite, from which he hauls coal to the agency.

Lignite in beds of workable thickness outcrops in the bluffs back of Elbowoods at a number of points.

The Old Fort Berthold Agency Flats.—About twelve miles below the present agency is the group of buildings that it formerly occupied. They stand at the upper end of a beautiful river flat, which contains some 4,000 acres. Its elevation is from twenty to eighty feet above the Missouri, which bounds it on the south. It is well grassed.

In the bluffs just east of the flat, a five-foot bed of good lignite is exposed about fifty feet above the river. On the opposite side of the river, in the broken ground back of Dancing Bear valley, a five-foot bed is mined by stripping. A four-foot and a three-foot seam outcrop in the bluffs a mile south of this mine.

The Fort Stevenson Flats.—These beautiful flats include about 7,000 acres, and lie on the north side of the river, a few miles northeast of Coal Harbor. Their elevation is from thirty to seventy feet above the Missouri, and its slope is gradual and uniform from the bluffs to the river.

Coal occurs abundantly in the bluffs just back of the flats. For many years lignite was mined here for use at the fort and Indian school formerly located here. The exact location of the mine was Township 148, Range 85, Section 35, southwest one-half. A seam said to be fourteen feet thick was mined by stripping. When seen the lower part of the excavation had filled in and only the upper two feet of lignite were visible. This mine is about thirty feet above the river flat. Higher up in the bluffs other lignite seams occasionally outcrop, the best exposures seen occurring half a mile east of the Fort Stevenson mine. Here three seams were noted, the thickest being six feet. Lignite outcrops also along two creeks in this locality. In Township

147, Range 84, Section 24, a lignite seam was visited, said to be eleven feet thick, though but seven feet could be seen at the time, the lower portion being covered with recent wash.

On the opposite side of the river seams three and four feet thick are nearly continuous in outcrop for ten miles.

The Apple River Flats.--Just south of Bismarck are extensive flats, which lie in the form of a triangle, the Missouri river lying on the west, while Apple river and the bluffs back of Bismarck form the sides on the east and north. They include some 5,000 acres, 2,000 acres being only from twenty to thirty feet above the river and partly wooded, while the remainder is from eighty to a hundred feet above river level. No coal outcrops in the immediate vicinity, but the expense involved in bringing lignite from the thick beds outcropping directly on the river sixty miles above, at Mannhaven and Coal Harbor, should not be great. It may be more practical to control the water of Apple river and use it for irrigation purposes, for the stream drains a considerable area and could doubtless furnish all the water needed if it could be properly stored.

On account of their situation on the outskirts of a city of considerable size, and on the Northern Pacific railroad, gardening should prove remunerative, and a rather high cost per acre to secure irrigation may be justified.

The Big Bend and Shell Creek Tract.—The Missouri river just before entering the Fort Berthold reservation receives the waters of the Little Knife. Then instead of pursuing its normal course it makes a notable bend like a great letter U. This portion of the river is known as the "Big Bend." Throughout this portion of its course and in the valley of Shell creek, which meets it at the lower end of the U, topographic conditions and the heavy beds of lignite present invite a careful study with reference to irrigation possibilities, though the conclusions that may be reached are probably more uncertain than in the flats already described. The area, however, is large, and the land lies wholly within the reservation and is still completely under government control.

The river at the "Big Bend" seems to have been diverted from its course at some time in the past, perhaps by the Wisconsin ice sheet, and compelled to cut a new channel to the west. Its former channel appears to connect the two arms of the U and form a valley two miles across, with its center, a third of a mile

across, sloping very gently and unbroken by gullies. Its position is shown on map I. At the upper end of the U this old valley is 140 feet above the river. Its slope is toward the south and the upper half drains into a large slough in its center, while the lower portion contributes its water to Shell creek. The area that could be irrigated advantageously, if water could be found, is two-thirds of a mile wide and fifteen miles long, including some 7,000 acres of good soil. In addition to this, on the Missouri, at either end of this old valley, are flats which contain 3,000 acres.

Six and a half feet of good lignite outcrop in the bottom of a draw about eighty feet above the river, and the bottom of the seam was not found. One-half mile down the river, in the bluffs at the point marked B, the following section is given:

	FEET
Lignite	5.5
Clay	5
Lignite	7
Clay	50
Water level.	

One hundred yards farther down a section partly covered by talus gave:

	FEET
Lignite	4.5
Clay	5
Lignite	3
Clay	50
Water level.	

The quality of the lignite in all of these beds was good.

Three and a half feet of good lignite outcrops in a cut bank known as "the slide." This same seam probably gives rise to the spring in the bluffs two miles to the north, where the Indians have dug through two feet of lignite to give freer vent to the water. It is persistent in outcrop for three miles to the south, though showing but few good natural exposures.

Although the exposures noted indicate a great abundance of lignite in seams from four to seven or more feet thick, the amount of the lift may render pumping from the Missouri out of the question. Shell creek drains more than 125 square miles, and its water may be available, at least for portions of the area, and for areas of 600 to 1,000 acres that are found along the valley of this stream. The flow of water in Shell creek on July 17, 1903, was about six second feet.

THE SMALLER FLATS ON THE MISSOURI RIVER, AND THE LIGNITE IN THEIR VICINITY.

Some of the many flats on the Missouri, limited in extent, but not so high as to render pumping from the Missouri out of the question, should be noted in addition to the more extensive tracts already described. Much of the woodland on the upper edge of the flood plain can doubtless be cultivated after clearing. Its soil is generally fertile and its value as timber land small. These tracts are not included, however, in the flats mentioned below.

On the south side of the Missouri, at the edge of the old Fort Berthold reservation, 1,200 acres, forty feet above the river. No coal showing in the immediate vicinity.

On Little Muddy Cut Off some ten miles below Williston, on north side of the river, 700 acres, twenty to forty feet above the river. Lignite six feet thick in the bluffs a mile below.

At Barker's Bend, a good flat of 600 acres, with twelve feet of lignite in "sliding bluff" just below.

Opposite Nesson, flats containing 1,200 to 1,500 acres from twenty-five to fifty feet above the river, with the heavy beds of lignite in Spanish Point already described three miles away.

Opposite the mouth of White Earth creek, an area of 600 acres, with three lignite beds, the thickest four feet, in the bluffs just behind.

Opposite the mouth of the Little Knife, 2,000 acres in two terraces, one twenty the other forty to eighty feet above the river. One lignite bed four feet thick was found in the bluffs behind this flat.

At the Indian village of Independence, 1,000 acres, eighty feet above the river. Lignite outcrops in a four-foot bed just across the river.

Five miles below the mouth of the Little Missouri on the east side, an area of 500 acres in two terraces, with lignite outcropping in a four and a half foot bed just opposite.

Just below the Fort Berthold agency on the opposite side of the river, a long narrow flat containing 2,000 acres, fifteen to twenty-five feet above the river, extending to Little Beaver creek, where four feet of lignite outcrop in the river bluffs.

Just above the town of Mannhaven, 1,500 acres, forty to fifty feet above the river. Eight feet of good lignite outcrop on the river at Mannhaven, with thinner beds, as shown in the following section:

	FEET
Lignite, good	6
Clay	2
Lignite	1
Clay	1
Lignite, good	2
Clay	10
Lignite, good	8
Sand	12
Water level.	

This section may be seen for 2,000 feet along the river.

At Hancock, 1,500 acres in a series of terraces fifteen to twenty-five feet above the river. Four feet of coal outcrop in the bluffs behind, while across the river the heavy beds once developed and known as the "Plenty" mine outcrop. The beds there exposed show:

	FEET	INCHES
Lignite	3	
Clay		6
Lignite	3	
Clay	2	
Lignite	3	

Mr. F. G. Mattoon is putting in a pumping plant to irrigate portions of these flats.

Two miles above Stanton, on the opposite side of the river, 1,000 acres, fifteen to twenty-five feet above water level. A seven-foot lignite bed outcrops close to the water on the edge of this flat.

Opposite Washburn, 3,000 acres in three terraces, at least portions of which are subject to irrigation. Six lignite exposures showing from three to seven feet of coal occur in the bluffs and coulees behind the flats.

The flats at Painted Woods Lake, 3,000 acres, with four feet of lignite in a neighboring draw and a five-foot bed exposed on a creek on the opposite side of the river, near Sanger court house.

At the mouth of Square Butte creek, eight miles above Mandan. Two feet of lignite are reported two miles to the north.

Near Mandan and at a number of points farther down the river are extensive flats, but no heavy beds of lignite are known to occur near them.

RIVER FLATS AND LIGNITE ON THE HEART RIVER.

Attractive flats, each containing a few hundred acres, may be found all along the Heart river and its tributary, the Green

river. Lignite outcrops along both streams are likewise frequent. Some of the largest mines in the state are located near them. The New Salem mines, but twelve miles north of the Heart river, during the year 1902-1903 had an output of 17,000 tons. Other mines producing extensively at Sims, are no farther from the river. Between New Salem and the river five-foot beds outcrop at a number of points and are mined on the strip-pit plan.

The mine of the Consolidated Coal company at Lehigh, three miles east of Dickinson, has developed a remarkably fine bed of lignite which varies in thickness from twelve to sixteen feet. It outcrops continuously along the river for three miles. Thirty feet above this thick bed, a three-foot seam is frequently exposed and above this another and more variable bed.

Lignite at Dickinson.—At two points on the outskirts of Dickinson lignite is mined in considerable quantities. At the plant of the Dickinson Pressed Brick and Fire Clay company, a five-foot bed is mined by stripping. The Lenneville mine, half a mile east of Dickinson shows a bed varying in thickness from four to eight feet. From this mine lignite ordinarily sells at the mine for $1.50.

Lignite on Green River North of Dickinson.—Throughout its course lignite abounds on Green river. Near its mouth at Gladstone beds of excellent quality, though not exceeding five feet in thickness, are found on the Rust and A. B. Powers' farms in Township 140, Range 95, Sections 26 and 27. The exposures are directly on the river and near water level. Two miles farther up the stream, in Township 140, Range 95, Section 22, west half, a three foot bed of good lignite is mined by the owner of the ranch on which it occurs. At the Kupper ranch, due north of Dickinson, a fifteen-foot bed of excellent lignite outcrops for a long distance on the edge of Green river. This bed is known to be very extensive.

Three and four miles west of Dickinson, on the Heart river, a four and a seven-foot bed outcrop frequently. The seam mined at the Bird-Stone mine, in Township 139, Range 98, Section 6, outcrops on the Heart river and may be seen from the cars of the Northern Pacific railroad. A sixteen-foot bed is mined, the upper part of the bed being inferior in quality at the outcrop. The lower eight feet is excellent. In Section 8 of the same township the bed outcrops again. On the south side of the

Little Heart, between South Heart station and Belfield, a six-foot bed of excellent coal occurs. It may be best seen in Township 139, Range 98, Section 16, a school section.

Coal North of Belfield.—Coal Mine creek, a tributary of the Heart river which unites with it a mile east of Belfield, shows great quantities of lignite along its course for at least five miles. Two good banks were examined, one in Township 140, Range 98, Section 28, six feet thick, and the other in Township 140, Range 98, Section 27, four feet thick.

A number of additional openings have been made along this creek from which lignite is taken. In Township 140, Range 99, Section 30, five feet of a bed said to be nine feet thick may be seen.

Lignite South of Belfield.—Three miles south of Belfield, on Norwegian creek, a tributary of the Little Heart which flows east and unites with the parent stream eight miles southeast of Belfield, a number of beds are exposed and slightly opened. They include:

	FEET
The Englehardson bank, Township 139, Range 99, Section 20	6
The Anderson bank, Township, 139, Range 99, Section 19	12

In the vicinity of all of these lignite outcrops there are flats of moderate elevation.

RIVER FLATS AND LIGNITE ALONG THE CANNON BALL AND CEDAR RIVERS.

Terraces of varying elevations and including considerable areas occur along the lower course of the Cannon Ball from its union with the Cedar and along both streams for sixty miles above their junction. On account of the meandering of the rivers and the rather limited width of the terraces, more than 600 acres are rarely found in a single tract. With the data now at hand it does not seem practical to irrigate areas larger than this by pumping from a single fixed station. It may be, however, that detailed study will show that two or more of these tracts may be connected by ditches and treated as one.

The elevation of the Cannon Ball flats varies from ten to eighty feet. The soil is generally fertile and many of the flats are well grassed. Some appear to be gumbo, while others are too sandy to be desirable for agriculture. Taken together they

present a considerable area, perhaps 30,000 or more acres with soil and topography favorable for irrigation.

As on the Missouri, there are opportunities for building reservoirs on the tributary streams and diverting the water so controlled to the flats of the larger stream. The difficulties here, as there, will be found in constructing at reasonable expense reservoirs sufficiently strong to withstand the strain put upon them by violent storms.

Lignite is not abundant on the Cannon Ball below Wade postoffice, where the Cedar unites with it. The following outcrops only were noted:

Three feet of coal reported in Castle or Palace Butte about six miles north of Cannon Ball postoffice, at the mouth of the river. Samples examined were of fair quality.

About eighteen miles from the mouth of the Cannon Ball, in Township 134, Range 81, Section 21, a fourteen-inch bed is mined by stripping. The outcrop occurs close to the river.

A bed two and a half feet thick is reported in a bank four miles northwest of Shields postoffice, and an equal distance from the river.

Three miles north of Howe postoffice a bed eighteen inches is reported.

A careful search made along the bluffs where good exposures occur brought to light only beds a few inches thick, till the upper Cannon Ball was reached.

Forty miles east of New England postoffice heavy lignite beds outcrop, and appear continually from this point for fifty miles up the stream.

The following beds may be briefly tabulated:

	FEET	
Township 134, Range 92, Section 31, O. S. Chase bank	2-3,	good
Township 133, Range 92, Section 4, E. C. Barry bank	3,	good
Township 134, Range 94, Section 21	3,	good
Township 134, Range 94, Section 22, NW¼	3,	good
Township 135, Range 96, Sections 21 and 22	4,	good

Near New England postoffice:

Township 136, Range 97, Section 22, Jacob Riess bank	7,	good
John Ermintrout bank, 6 miles N.E. of New England	3	
Five miles west of New England, directly on Cannon Ball river, in two beds, good	9	

On Coal Bank creek, a tributary of the Cannon Ball, which unites with it near New England, shows good lignite beds frequently. One four-foot bed may be found four miles from the mouth of the creek.

On the upper Cedar river lignite is said to be abundant, and from observations on the adjacent tributaries of the Cannon Ball the reports are probably correct. The same statement can be made for the upper Grand river in South Dakota.

RIVER FLATS AND LIGNITE ALONG THE LITTLE MISSOURI, ABOVE MEDORA.

Terraces are well developed along the Little Missouri at nearly every point in its course. In a given locality their number may be five or six, while few localities have less than three. Their elevation varies from twenty to 200 feet above the river. No single tract is large on account of the meandering of the river, but the total area at an elevation moderate enough to make pumping from the river practical is considerable. A rather careful estimate of the area not more than thirty feet above the river places it at more than 30,000 acres, cut up into tracts ranging in size from fifty to 1,000 acres.

During the summer of 1902 nine townships on the upper course of the Little Missouri, with Yule postoffice as a center, were studied. The topography of the country is diversified, including the LittleMissouri valley and its terraces, the "breaks in the vicinity of the river and the rolling country back from the river which furnishes an unequaled summer range for cattle. Lignite outcrops even in the shallowest of coulees. Ranchmen seldom find it necessary to go far for fuel. Many of them consider it easier, however, to go to the river in winter and break up the great blocks of coal that the stream has washed out. More than half of the area had not been surveyed in September, 1902, and in many cases it is impossible to cite locations definitely.

In Range 105, Townships 133 and 138, which includes an area from twenty to forty miles south of the Northern Pacific railroad, a number of coulees head, which flow eastward into the Little Missouri river. In going from north to south, Williams, Garner, Bullion, Horse, Coal Canyon, Cannon Ball, Boise and Bacon creeks are crossed in about the order named. All of these creeks show lignite more or less continuously from the time that they cut through the sod until they empty into the Little Missouri,

their courses varying in length from ten to twenty miles. None of these creeks, except Cannon Ball, are shown on an ordinary map.

Lignite on Williams Creek.—Six miles from its mouth the following section is given:

	FEET
Lignite, good	2
Clay	20
Lignite, good	4
Clay	4
Lignite, one foot exposed and bottom of bed not found.	

These beds were traced for a mile along the creek. Along the lower course of the stream lignite is said to be abundant.

Lignite on Garner Creek.—Exposures not abundant, though springs that probably come from the lignite are common, the lignite being concealed by the grassed slopes. A tributary which unites with the creek eight miles above the Little Missouri is said to show a four-foot bed.

Lignite on Horse Creek.—For more than six miles along this creek lignite beds varying in thickness from three to six feet are exposed at various elevations.

Lignite on Coal Canyon.—An abundance of lignite is exposed along the deep ravine through which this stream flows. A typical section is as follows:

	FEET
Lignite, fair	5
Clay	1
Lignite, good	7
Clay	1
Lignite, good to creek bottom	1

This exposure occurs two miles west of the Little Missouri.

Lignite on Cannon Ball Creek.—This creek empties into the Little Missouri about twenty-five miles south of Medora and is a stream of some importance, its valley being nearly a mile wide one mile from its mouth, where six feet of good lignite outcrop in a single bed. Along the Little Missouri and its tributary ravines in this vicinity four and five beds of lignite may be seen, ranging up to four feet in thickness.

Lignite on Boise Creek.—Some miles above its mouth two and three beds were seen ranging from two to four feet in thickness.

Lignite on Bacon Creek.—At the J. C. Gamel ranch in Township 133, Range 104, Section 20, a bed twenty-four feet thick outcrops. Its quality is good.

Lignite on Sand Creek.—A lignite bed *forty* feet thick outcrops near the A. E. Russel ranch, in Township 135, Range 101, Section 31. The exposure is continuous along the creek for a quarter of a mile, and much of the coal can be won by stripping less than ten feet of earth from the surface. At the north end of the exposure the section given was:

	FEET
Sandstone	2
Clay	10
Lignite	2
Clay	2
Lignite	15
Clay to water level	3

At the south end of the exposure the lignite reached the remarkable thickness shown below:

	FEET
Clay	5
Lignite	3
Clay	2
Lignite	40

The lignite throughout the bed appeared to be of good quality, except the upper two feet, which are soft. The analyses of this lignite indicate that the quality is good.

Lignite on the Little Missouri Near the 777 Ranch.—Some fine beds outcrop in this vicinity, which is some miles south of Yule. Rising directly from the water's edge at one point, the beds of clay and lignite reach a height of 110 feet. The heaviest lignite bed in the section is the lowest, which is more than twelve feet thick.

Lignite at Yule.—Two and three beds of fair thickness and quality occur near the postoffice of this name and at points between it and Medora.

Well developed river flats occur along the Little Missouri in this vicinity and at times exceed 500 acres in extent.

Both north and south of Medora for a number of miles lignite is as abundant as at the points cited. At some points, as near the Eaton ranch, it is mined for local use.

PRESENT STATUS OF IRRIGATION IN NORTH DAKOTA.

A great part of the irrigation in North Dakota is due to the stimulus given by the Desert Land Law. The application of this law in the state seems to have been free from abuse, and a further application of it has been prevented by the fact that exten-

sive areas in the semiarid portion of the state are not recognized as desert land by the land office. The only portion of the state where desert land claims may be filed is the northwestern, and here there is always some uncertainty as to what the ruling of the land office will be till each claim is finally inspected.

On the Yellowstone flat in North Dakota and just over the line in Montana the following claims have been filed:

Andrew F. Noble has a reservoir on Four Mile creek, a tributary of the Yellowstone in Montana, close to the boundary line. Four Mile creek is said to have a drainage area of twenty-four square miles, and the Noble dam when completed will be twenty feet high in the center and the reservoir when filled will have a surface area of 388 acres.

A. W. Mann has a claim in Township 152, Range 104, Section 31, S. E. ¼, and proposes to obtain water from draws in the bluffs behind.

Sarah and Kate Mercer have desert claims on Township 152, Range 104, Section 32, N. W. ¼, and Section 31, N. E. ¼, and obtain water from draws. The main ditch to control these areas is already constructed.

On the Buford-Trenton flat, Mr. Edward Jack (postoffice Trenton) has been foremost in the effort to secure water for irrigation. Associated with him are Carl Wittmeier, Grant Conley and Charles Schumaker. A dam on Eight Mile creek which comes down from the north and spreads out over the Missouri bottom lands three miles west of Trenton, has been constructed across the creek bed, and the reservoir so formed has a surface area of 75.4 acres, and a capacity of 521.5 acre feet. The dam is of earth faced with stone, and has a suitable flume and waste gate. Its present capacity is regarded as sufficient, aided by the rainfall and inflow during the irrigating season, to care for 400 acres. The dam has washed out twice and has been rebuilt each time in a more substantial manner. Up to the present about $8,000 have been expended on reservoir and ditches. The results already obtained have satisfied the owners that the outlay is justified. The capacity of this reservoir could be increased considerably without great expense, and it is probable that water from Eight Mile creek would still fill it, if its capacity were not much above 1,000 acre feet.

Irrigation on Little Muddy Creek Near Williston.—The most notable attempt to irrigate in the vicinity of Williston was made

Fig. 1. Sandstone at the top of the Blue Buttes

Fig. 2. Lignite at Mannhaven, exposed along the river

a few years ago by Mr. Fred Rounsaville of that place. On the Little Muddy, ten miles above Williston, in Township 153, Range 100, Section 5, he constructed a dam to divert the water from the stream and throw it into a lateral ditch which would irrigate the flats on the right bank of the Little Muddy and possibly a portion of the flats at its mouth, on the Missouri. No attempt to store the water was included in the plan. The dam was constructed and a portion of the ditch, when the work was stopped by the death of Mr. Rounsaville. The property is now offered for sale.

On the Little Muddy, above Williston, and its tributaries the following persons are irrigating to some extent, the operations for the most part being limited to spring flooding for grass.

George Marelius and Stephen A. Marmon have a reservoir in Township 159, Range 101, on Black Tail creek, a tributary of the Little Muddy from the west. They are said to be flooding 1,200 acres both for grass and grain.

The Freeman family are constructing a reservoir on the upper course of the Little Muddy, in township 158, Range 100, Sections 20, 23, 29 and 30 and are planning to irrigate 1,900 acres.

In Township 155, Range 98, Sections 28 and 29, Ellen Adams has a desert land claim which is now proved up. Water is taken from coulies that are dry in summer and the irrigation is for grass only.

Joseph Lansford has 320 acres which he irrigates in Township 157, Range 100, Sections 21 and 27, on the upper Muddy.

F. R. Zahl, in Township 159, Range 101, Sections 24 and 25 at the mouth of Scoria creek, a tributary of the Muddy, with his family, holds a section which he irrigates for grass.

On Cow creek, a tributary of the Muddy, L. L. and Howard Lampman irrigate two sections in Township 156, Range 102.

James Sherry, on Stump creek, a tributary of the Muddy from the west, in Township 156, Range 102, Section 2, irrigate a twenty-acre garden by pumping from a reservoir in the creek. During the year 1903 he pumped only four days, this with the rains being enough to mature a full crop of garden truck. An eight-horse power gasoline engine lifted 800 barrels an hour twenty feet. With gasoline at thirty cents a gallon the cost of operation per day of ten hours was $3. The owner estimates that, with the rain of an ordinary year to assist, his plant is capable of irrigating 160 acres. The soil is a sandy loam with clay subsoil. The cost of pump, pipes and engine delivered at

Williston was $811. Mr. Sherry has great faith in the profit to be derived from the enterprise and will extend the area that he irrigates next year.

Mr. E. A. Sharpe, on his farm two miles northeast of Williston, in Township 154, Range 100, Sections 17 and 20, is installing a ten-horse power gasoline engine and a centrifugal pump, which for his lift of ten feet has a claimed capacity of 735 gallons a minute. He intends to irrigate for grass and grain. Water will be taken from Stony creek and Little Muddy river. He estimates that he can irrigate 200 acres with his plant and that thirty days will be a maximum number for operation in an ordinary year.

At the mouth of Cow creek, on the Big Muddy flats, the Hedderick (formerly the Voss) ranch irrigates extensively for grass.

On Camp creek, in Township 155, Range 102, R. M. Calderwood, Grant Greenup, Francis Hendrickson and others have filed desert land claims and have made preparations to irrigate extensively.

At the mouth of the Little Knife Mr. Black has irrigated with profit for grass for a number of years.

Irrigation on Nelson Creek Near Nesson Postoffice.—The Nelson ranch, at the mouth of Nelson creek; on the upper terrace, is an illustration of the possibility of irrigating the upper terraces at that point at a moderate cost from the creeks coming from the upland. An earth dam at the mouth of Nelson creek diverts the water and by laterals it is spread over a considerable area, so that 600 acres or more are flooded in the spring. The ground is thoroughly soaked to a depth of two feet and is then allowed to stand a week before cultivation. On land so prepared oats often yield sixty bushels to the acre and wheat twenty-five, while the surrounding country, as favorably located except for the flooding, yields from nothing to ten bushels.

Irrigation on Beaver, and Its Tributary, Dry Fork, Creeks.—One of the earliest attempts at irrigation in North Dakota was made at the old Grinnell ranch at the mouth of Beaver creek, where by dams and ditches the water from the creek was spread over a number of hundred acres of the lower Hofflund flat. Part of the same area is irrigated in the same way by H. A. Carey. Carey's dam is twenty feet high and is not intended to store water in the creek bed back of it to any considerable extent, but

to divert it to the laterals during the abundant water of the spring.

Ole Barsted has a dam and ditch on Dry Fork creek near its junction with the Beaver, and higher up on this creek are the dams of Wallender and Manly Anderson.

On Beaver creek above Carey's, water is diverted for irrigation by Nels J. Camp, Wm. Barsted and George Littlefield.

Mr. Ward is irrigating the east end of the lower flat at Hofflund, at the old Lampman ranch.

Mr. F. G. Matoon is putting in an extensive pumping plant to irrigate a portion of the fine flats on the Missouri at Hancock postoffice.

Irrigation as practiced at present on the Little Missouri and Knife rivers will be noted by Mr. Wood in his report.

RECOMMENDATIONS.

Opportunities to make application of the conditions of the Reclamation Act seem to exist in the larger flats on the Missouri river. A peculiar phase of the problem, however, is found in the fact that much of the land in these flats is already in private ownership. The flats which lie within the Fort Berthold reservation form the only exception to this statement.

In choosing among the Missouri river flats for one where the pumping plan may be tried under most favorable conditions, a number of factors must be kept in mind. Nearness to a railroad and a market are as essential as an abundance of cheap fuel and good land. An active interest on the part of the resident owners is necessary where the land is already in part or wholly private property.

With these conditions in mind, the flats at Buford and Trenton and the Nesson-Hofflund tract deserve first consideration. The former lies directly on the railroad. Lignite is not abundant here, however, and will cost about $2 a ton, whether mined in the vicinity or hauled from Williston. The Nesson-Hofflund flats are fourteen miles from the railroad; are wholly taken as private claims by parties eager to receive aid in irrigating; lignite is very abundant and should be laid down at the pumping plant for $1 a ton. It may be possible to locate the pumping plant within a few hundred yards of an extensive outcrop. From an engineering point of view, the Buford-Trenton tract seems somewhat simpler, though this must be left for the judgment of experts.

If a pumping plant is located at one of these points, it should prove whether the plan is practical for a hundred similar localities in the western part of the state.

The Big Muddy river above Williston deserves study. If a reservoir site can be found, the flats on this stream can be provided with water and an urgent need on the part of the settlers in the valley, who claim to be ready to pay a fair price for water, will be met.

The Yellowstone flats in North Dakota form the most attractive single area for irrigation in the state. Since the gradient of the Yellowstone is somewhat higher than that of the Missouri, it may be practical to divert water from the river by starting well up in Montana. If this should prove too expensive, water may be moderately elevated by pumping at Sidney, Montana, where heavy beds of lignite are said to exist. From this point the water would be of constant service, both in Montana and North Dakota.

OBSERVATIONS ON THE GLACIAL DRIFT.

On the Cannon Ball river the extreme western limit of the glacial drift seems to be about ten miles west of the mouth of the Cedar river. For many miles east of this point the drift is represented only by boulders, which in places are quite abundant, as is shown in plate VII., which is made from a photograph taken on the Cannon Ball river, ten miles from the edge of the drift. The boulders here as everywhere near the edge of the drift lie directly on Laramie clays. Beyond the drift, in the southern part of the state, particularly in the Cannon Ball country, fragments of quartzite, which is regarded as residual, are very abundant, often literally paving the hill tops.

About Coal Harbor, which is eighty miles north of Bismarck, there are rather positive indications that an older Wisconsin drift occurs, which probably crosses the Missouri here and at points farther north. Unmodified and rather fresh drift is here found in the Missouri valley only a few feet above present high water. The topography of the upland at Coal Harbor is not more mature than that of the Iowan drift.

A more elaborate discussion of drift phenomena in the western part of the state is given in Mr. Wood's report.

Boulders on the Cannon Ball river, ten miles from the edge of the drift

REPORT ON THE REGION BETWEEN THE NORTHERN PACIFIC RAILROAD AND MISSOURI RIVER. ITS TOPOGRAPHY, CLIMATE, VEGETATION, IRRIGATION POSSIBILITIES AND COAL DEPOSITS

BY L. H. WOOD

INTRODUCTION

The area treated in this report lies in the extreme western part of the state, and comprises the river areas between the Northern Pacific railroad and the Missouri river. The parts more especially studied were the valleys of the following streams: The Little Missouri north of Medora; the lower ten miles of Beaver creek; the flats of Cherry creek in the vicinity of X ranch; Knife river and its tributary, Spring creek, and, lastly, Farmer's valley and Deep creek north of Taylor and Richardton. The two chief purposes of the work, the study of the problem of irrigation and the lignites with reference to their use in irrigation, naturally confined the attention of the party to the flats along the principal streams.

Plan of Work on the Little Missouri.—The lack of continuous roads along the river and the extreme roughness of the uplands made it necessary to plan the trip by boat. We learned at Medora that this scheme was considered impracticable, if not impossible. No one had ever made the trip in this way, and the reported drying up of the stream during the summer months to a series of pools of stagnant water, together with the record of the Missouri survey party, that the lower end of the Little Missouri had been seen dry, did not seem to warrant that the party would ever reach the mouth of the stream by boat. Whatever misgivings may have been entertained the experiences of the first two weeks were poorly calculated to remove. When the boat was loaded with the supplies it was found to draw twelve inches of water, or more than the average depth of the stream. By good fortune we were able to send the larger part of our baggage to the mouth of Beaver creek, where we arrived two weeks later after pulling, tugging and lifting the boat over long and frequent sandbars. Almost continuous wading was necessary over

stretches of miles in length, and reaches where rowing was possible for more than a mile without encountering bars were rare. As a rule the channel follows the cut-bank, with a depth of two or three feet of water for a half mile or more, and then, in passing to the cut-bank on the opposite side, spreads out, fanlike, depositing its load of sediment along lines that frequently shift in a direction transverse to the flow of the stream. Very often the river divides into two nearly equal streams, one of which again subdivides into parts further down the flank of the broad, flat sandbars, each minor stream making its way back to the undivided partner on the opposite side of the bar at the first opportunity. Again, both parts of the divided stream interlace in a maze of sandbars, making it almost impossible for the boatman to thread his way through the uncertain depth of water. But perhaps the most troublesome habit of the river was that of dividing about equally at the head of a bar a mile or more in length, one of the divisions having no outlet below. At such places a sluggish current, due to low water, made it frequently impossible to tell which was the living channel; and several times the party found itself in one of these pockets of stagnant water, from which the only outlet was a return to the head of the bar. The prevailing muddiness of the river made it necessary for one person to be continuously on duty at the bow of the boat, where, by striking out to the right or left with a long pole he was able to keep to the deeper part of the channel, which often became so narrow that the boat would pass only by being propelled from the rear.

The slightest weakening in the velocity of the heavily loaded stream was followed by a deposition of sediment at all parts of the channel, even when the water was high, and once the boat struck on a sandbar when the water a few feet away was from six to ten feet deep. Not the least of the dangers to which our course was subject in this fitful stream, were the narrows under the lee of the bluffs. At these points the river usually contracted to a width of but a few rods, while the channel was generally full of boulders of sandstone and coal through which the current ran swift and deep. At a few places concretions of ferruginous sandstone jutted out ridge-like into the stream, producing swift rapids with deep pools below them. At such points the only course was to shoot the rapids, where, in attempting to

Roosevelt's old ranch, twenty-eight miles below Medora. (His other ranch, from which his old cabin was removed to St. Louis for exhibition purposes, was situated above Medora)

avoid catching on the reefs of sandstone, we ran the risk of capsizing on sunken rocks.

On the whole, the river did not give us the trouble from lack of water that the experience of the first few days had led us to expect. Even where the channel was but a few inches deep there was generally a strong current that greatly facilitated dragging the boat over many long reaches where it would not float. Running water was found over the entire distance, and due to opportune showers the depth of water increased after the first few days out, so that by the time Beaver creek was reached there was an abundance. Two weeks later, or about the 20th of July, the stream was again running very low, rendering progress somewhat slow for the last sixty miles of our course. But on the 22nd and 23rd of July heavy showers occurred that raised the river five feet in one night, and carried us out to the Missouri in from ten to twenty feet of water where we had expected to find dry land.

The plan of work followed along the stream was determined by conditions encountered. During the forenoons the party was divided for a study of the creeks on either side of the river; while in the afternoon, this part of the day being chosen because wading was then more pleasant, all were kept busy in getting the boat further down the stream. In this manner a considerable portion of the country on each side of the stream was examined by the members of the party. Where the nature of areas closely related to the Little Missouri valley seemed to invite it, several longer excursions were undertaken to the right or left of the stream. Beaver creek was visited ten miles above its mouth; the widest part of the bad lands, in the vicinity of Roosevelt's old ranch, was penetrated some ten miles or more, by one of the party; the Yellowstone divide below Beaver creek was reached; a considerable part of the area called Cherry flats was seen; and one day was spent in the study of the Kildeer mountains. Also, while making the trip in the Knife river valley, the Little Missouri country was again approached and visited at the head of Magpie creek at the Simpson ranch, and again on Hans creek below the Anderson ranch.

Work on Knife River.—For this part of the work preparations were made at Mannhaven July 29th and from this place the party set out by wagon toward the south and west. Knife river was struck three miles below Hazen and followed to the mouth of

Spring creek, whence the route led along the creek to Halliday and Oakdale; then southwest by the headwaters of the Little Knife, and east to Fayette; from Fayette the course followed passed to the head of Knife river, over the divide to the head of Magpie creek, again south and east to Dickinson, Gladstone and Taylor; thence by the way of Farmer's valley and Deep creek to Rock Spring on the Knife river. From Rock Spring a trip was made up Crooked creek to study the flats along the lower course of that stream. Starting east from Rock Spring the valley of Knife river was followed continuously to a point eight miles below Hazen, where the trail to Mannhaven was again taken up.

The Survey was fortunate in securing the services of Mr. Pease and Mr. Goodall, students from the University of North Dakota; the former rendering excellent service through his intimate and accurate knowledge of the trails of the region, the latter by his painstaking care in making the photographs of the area. Both took no small part in working out the details of the hydrographic and physiographic problems of the region.

The pages that follow are given to a consideration of the topography of the area, to roads, settlements, possibilities for agriculture, irrigation and accessibility of the coal lands. The climate of western North Dakota is considered with reference to agriculture and stock raising, and a brief notice is taken of crops adapted to the region. A few special problems, such as conditions under which the coal was formed, effect of the drift and problems of valley formation, herein briefly discussed, would, it is believed, richly reward further studies undertaken purely from the scientific side.

It is necessary to say for the map which accompanies this report that it is not intended to represent exactly the topography found in any one small part of the area, but to give a general idea of the surface in respect to relative elevation, roughness, breaks as compared with flats, position of coal outcrops and the location of the more significant features. With respect to localities it is believed that the map is fairly accurate since, so far as possible, town, range and section were considered in the preparation. No maps yet made of the area are found to be accurate, and for the Little Missouri region no exact map can be made, since much of the area is yet unsurveyed. So, while the map cannot be used as a road guide, it is hoped that it may convey to

Difficulties on the Little Missouri

the person interested in the region some better idea of it than could be obtained from the ordinary map. It is constructed roughly as to scale of elevation, the basis being the height of the area with reference to the Missouri river at Bismarck.

CULTURE.

Under this heading are included the following subjects: Area compared with eastern North Dakota; location of dwellings; farming and grazing areas; roads and trails; post-offices.

The one thing that most impresses itself upon the tourist in eastern North Dakota is the openness of view out over countless acres of broad prairie. The houses, with their small patches of sheltering copse, stand out conspicuously on the plains, with nothing but waiving fields of grain to hide them from view. Along the Red River, for forty or fifty miles on either side, farm lands, as level as a lawn, stretch out in the distance as far as eye can see, dotted with houses which seem to be as uniformly placed as the township lines; and with no fences, or hedgerows, or hillocks to intercept the view, one feels that he is upon a sea of land. At night, in the autumn, one may see the blaze of a dozen burning straw stacks lighting up the horizon. Yet here the population is not dense, for many a section goes untilled, and many more are but imperfectly cultivated. Nature has blessed the land with the richest of soil. The contrast between this area and the Little Missouri country is sharp. No houses are seen on the uplands bordering the valley. In every direction dry, sunburned grass lands and barefaced clay buttes alone relieve the monotonous upland plains. As one scans the horizon, viewing some especially broken part of the bad lands, not a living thing is visible as far as eye can penetrate the maze of yellow and gray, clay buttes; nothing but sunburned grass, bare, steep-faced gorges and red, burned clay met the gaze in every direction. Miles of broken land stretch between the scattered dwellings of the ranchers; for sites for buildings are not determined by section lines, but rather by the irregular placement of the valleys where shelter may be obtained. Where the uplands are flat, extensive grazing lands replace the waving grain fields of the eastern half of the state. The two regions, the one east and the other west of the coteau of the prairies, are sharply set off from each other, the former adapted to farming, the latter

practically valueless except for the pasture afforded by the thousands of square miles of upland prairies.

In the region of the Little Missouri the valleys alone are occupied. On descending from the bad lands or the upland flats to the lower levels along the streams, the aspect changes decidedly. The life that has fled from the scorched and bare hillsides is found crowded along the water courses. Here forests of poplar, dense growths of shrubbery, birds, insects, wild beasts, and man himself have sought the protection afforded by the walls of the valley from both the scorching summer sun and the chilling northwest blasts of winter. Here is also found the water so necessary for the herds which graze on the plains above. It can be truly said that the life of the region clings to the ground water level, which lies, for the greater part of the year, several hundred feet below the upland plain.

Ranches are found at intervals of three or four miles along the Little Missouri, located either on the river side or at springs, some of which are miles from the main valley up along the creeks. Claims in the Little Missouri valley are held largely by squatters' rights and boundaries are not defined. The settler secures a good watering place, or a protected spot for his stock sheds, or, remote from the streams, a good spring, and the mere matter of acres of land is a thing that, so far, takes care of itself. In years past several points along the river were occupied by larger ranching companies, such as the W, the X, the Diamond C, and very large herds of cattle were gathered upon the grazing lands; but at the present time, due to reverses and to overfeeding on the grass lands, the larger companies have either left the region, or are represented by small holdings only. Along some reaches of the river smaller ranches are placed somewhat too frequently at the present time to suit the demands of grazing, and due to the crowding in of new settlers the danger of overfeeding and consequent destruction of native grasses is imminent. Some system of supplementing the natural resources of the hay and grass lands is badly needed, and especially a more systematic apportionment of the grazing lands.

Holdings along the valley of Knife river and Spring creek are obtained by purchase or by homesteading. Several claims here cover more than 2,000 acres, besides the use of the unoccupied adjacent grasslands. Some of these holdings include lands along the creeks, which a system of irrigation will make very valu-

able. The lower courses of the stream above mentioned, in the vicinity of Hazen and Stanton, and the adjacent uplands near Krem and Mannhaven are much more fully occupied. Around Krem some excellent crops are raised by a system of dry farming which the Germans of this area practice with great success. There is probably much more land southwest of Krem that is adapted to this sort of farming. The area in question is that over which the glacial ice has passed, the natural clays having been mixed and made far more porous, and thus capable of absorbing and holding the rainfall for a greater length of time than the impervious clays of other parts. This capacity to hold the moisture for some length of time makes it possible for the growing plant to use the part not lost by evaporation.

Several good farms were noticed in Farmer's valley, and also on the more sandy uplands north of Dickinson and Gladstone. It seems not unlikely that small areas will be found, even along the uplands of the Little Missouri, where dry farming would yield good crops two or three years out of five. The annual rainfall, though small, comes largely in the growing season, as will be shown later, and crops which get a good start have a fair chance of coming to maturity.

Dwellings.—The finest buildings in this area, outside of the towns along the Northern Pacific railroad, are those of the German settlement in the vicinity of Mannhaven. Here the sod houses of the earlier settlers have given place to well built farm houses one and two stories high. There are also large, well kept barns and substantial sheds for stock. Two churches stand out conspicuously in this locality, the only ones seen north of the railroad, forming sightly landmarks visible for many miles around. Several local stores supply the immediate wants of the farmers. Along Knife river and Spring creek the dwellings are also of a substantial sort, built mostly of lumber hauled from towns on the Northern Pacific railroad. They are usually of one story, since that is found to be the best form to weather the severe winters; and they are generally placed in some well protected part of the valley and screened more or less by low spreading box elders and white ash. It is along the more inaccessible Little Missouri that the houses retire into the more primitive class. Here lumber is scarce, the nearest towns are fifty or sixty miles away, and the roads are very poor. As in other areas the ranchers want the best, and are able to have it, but so far

low, one-story log houses are found to meet all the requirements of comfort. Protection for stock is found in the draws and timber land along the river rather than in large and well kept sheds. Houses for both man and beast are largely extemporized. Poplar and red cedar is abundant, so that many of the buildings are constructed of these materials. The sheds are constructed of these materials. The sheds are built in the fashion of a stockade, part of which is roofed over with a capping of bushes and hay. The houses are substantially built from logs, either in the fashion of an ordinary log house, or with logs set on end to form the side walls, which are afterward made tight by a plaster of gumbo. The roofs are of various sorts, some of shingles, others of dressed cedar logs covered with burned clay, and still others buried under a layer of earth. While the use of much undressed material gives the house rather a rough exterior, the inside often presents a cosy, inviting appearance, with furnishings adapted to the needs of ranch life.

But one school house was seen in all this region, and this was the property of a few enterprising ranchers living below Rock Spring. This small building, dismantled of its furnishings, is now on the land of Mr. Paulson. The ranchers with families live so far apart that it is cheaper to send children to school at towns along the railroad than to hire a teacher.

Roads.—The roads most traveled are the mail routes from towns on the Northern Pacific railroad to the postoffices of Knife basin, Hazen, Broncho, Halliday, Rock Spring and Oakdale. Roads from these places, with connecting cross trails, run to Hebron, Taylor and Dickinson. Branching off from these roads, trails extend along the valleys from east to west to ranchers more remote from the mail routes.

The postoffices are subordinate centers from which roads and broncho trails extend in many directions. The mail routes, together with the more traveled roads, make it possible to get to most parts of the region with light rigs or on horseback, but the hauling of large loads is a serious matter. Bridges are rare, and crossings good at one season may be washouts at another, where mud makes the roads impassible. It is not an uncommon thing for a man to be obliged to unload his wagon and transfer it by peices from one side to the other of a bog that has developed in the roadway. The steep hills along the streams with the sharp pitches at the creeks need much grading

before some parts of the region can become readily accessible. The hills of the Little Missouri valley are especially steep, and the narrow branches along the creek valleys where the roads must pass are most liable to washouts.

The principal trails are indicated on the map which accompanies the report. While they are not correct when compared with section lines, they serve to indicate the general direction along which one may find his way to various parts of the region.

TOPOGRAPHY

General.—The region presents two general types of relief. One of these types, the bad lands, is in the main driftless and coincides for the most part with the Little Missouri basin south and southwest of the Indian Reservation; the other, included within the basin of the Knife river, has had its surface greatly modified by ice action. Neither area, however, is at all uniform either in respect to bad land distribution or to modification by the ice; for both areas have bad lands and both have been affected, but to different degrees, by the results of ice action. The contrast is, nevertheless, very decided, and is strikingly portrayed to one viewing the two areas from the top of the Kildeer mountains at Oakdale. From this point, which is five hundred feet above all the surrounding country, one looks out and down upon the plains, and is able to distinguish outlines of relief sixty miles away. A line running from the southwest corner of the Indian Reservation to the Kildeers, and from there to Taylor, may be taken as the division between the two types of typography mentioned above. To the east of this line the entire area is more or less broken, being about equally divided between low hills of irregular outline, and rather wide basin shaped valleys. A glance to the southwest shows what was once a broad plain extending at a uniform level as far as eye can see. Here and there upon this surface a low hillock rises perhaps a hundred feet above its surroundings and marks the position of what was formerly a stately butte, its summit high above the surrounding level, now crumpled and wasted away to but a mound upon the plain. Farther to the west and south the basin of the Little Missouri is hemmed in by a more lofty wall of buttes that crowns the divides on either side of the valley. This broad upland plain lies at a level five hundred feet below the top of the Kildeers, which rises wall like on its eastern mar-

gin. Down 600 feet below the surface of the plain is the channel of the Little Missouri; and at irregular intervals along its course the plain breaks away into singularly patchy groups of pyramidal hills whose tops lie, for the most part, a little below the level of the grassy upland plain from which they have been carved by the torrential rains. These groups of buttes, gray, yellow and white, remarkably uniform in shape and size, stand out in strong contrast to the dark brown and green plats of vegetation that hem them in on every side.

The striking features of the topography are the wide stretches of upland flats, the deep valleys of the streams, and the breaks along the courses of the creeks. While the topography here is more sharply defined, and its parts more strongly contrasted, it is much less complex than that east of the Kildeers. Along the Little Missouri there is much very flat upland with the same general level; while along the Knife low rounded hills and broad valleys occupy most of the surface, and the barefaced buttes so common on the west, are less often seen in the larger part of the Knife and Spring creek basins. The valleys of the streams are also greatly unlike, (see figure 1) for those of the Little Missouri region are broadly U shaped with extremely steep slopes, while high bluffs are generally absent from the valleys of the streams at the east.

The area to the east of the Kildeers was doubtless not unlike that of the Little Missouri basin in preglacial days. Now its steep slopes have been greatly toned down, and its flat, upland surface roughened by ice action. In some parts it seems to be a tumultuous sea of hills, with an entire lack of uniformity, either of size or manner of placement, so that the area presents a typography of peculiar type, and though with less relief. it appears, in the distance at least, to have a rougher surface than lands on the west.

In elevation, likewise, the two areas are somewhat in contrast. The country east of the Kildeers rises gradually from an elevation of 2,200 feet at the Missouri to 2,500 at Oakdale; while the Little Missouri valley maintains for the most part along the river an elevation of 2,500 feet, so that the stream channel lies much more below the level upland northeast of the Killdeers than at Medora, bluffs at the former location being about 550 feet above the river, and 250 to 300 feet at the latter. In both areas the elevation falls off rapidly within the margin of the drift.

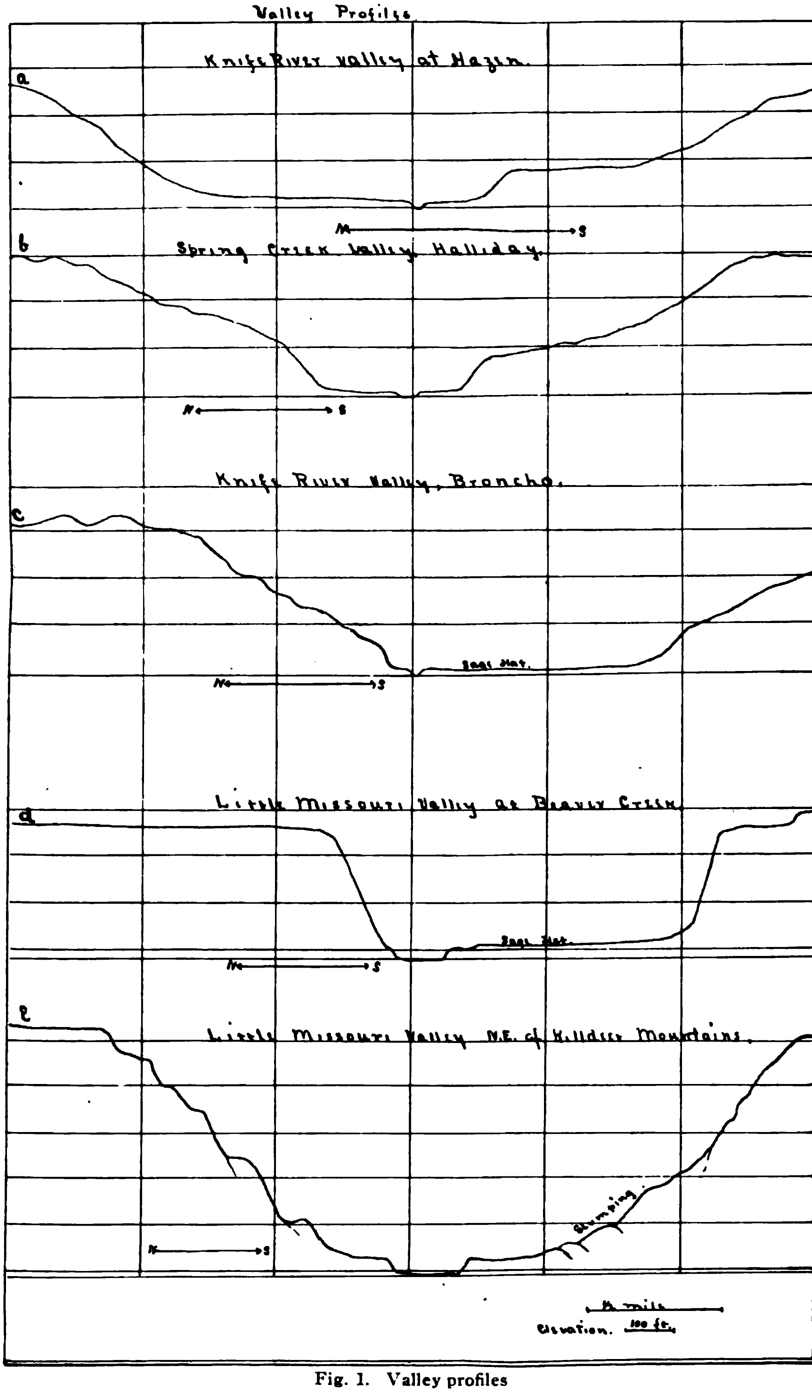


Fig. 1. Valley profiles

TOPOGRAPHY OF THE LITTLE MISSOURI REGION

Valleys. The valley of the Little Missouri, as well as those of its tributaries, is broadly U-shaped. Since the valley is the product of a long erosion period we should expect to find the uplands grading off to the level of the stream by gentle slopes. Such is not the case, however, for the aridity of the climate has entered as a large factor in the erosion history of the whole region, with the result that the cutting due to lateral work has been reduced almost to zero. The slopes of the stream rise abruptly from the terraced floor of the valley, at an angle so sharp in many cases that the bluffs cannot be climbed; and the effect of these slopes, rising like two walls on either side of the stream, is to set it off sharply from the broad, flat upland plain. From Medora to the Missouri the valley is not unlike a great trench, with steep faces and a broad, flat bottom cut in a level plain. In width the Little Missouri valley averages three-fourths of a mile, ranging from a half mile to a mile and a half from bluff to bluff. The walls rise 300 feet above the upper flood plain at Medora, gradually increasing in relative height to a point north of the Kildeers, where the upland level is 550 feet above the river. The flats vary in elevation above the stream from a few inches to forty feet.

Sage Flats. This term is applied to flats that lie in general about twenty feet above the river. They are usually sage covered, without forests or trees except for the margin of shade along the river, and have a remarkably smooth surface that slopes gradually from the buttes in the rear down to the river where they usually terminate in a vertical cut bank.

Wooded Flats. The flats lower than the sage flats above mentioned are mostly covered with forests of cottonwood and with bushes. They have an irregular surface due to the presence of remnants of the old channels of the river and are prevailingly sandy, which further unfits them for cultivation. In many places freshly blown dune sand is contesting with plants the right of way on these flats. Their margins are inundated at higher floods, while the streams are in many places cutting laterally into their margins, removing material for deposition elsewhere. The progress of the river cutting is somewhat retarded at many points by the rapid growth of willows, whose roots, ever seeking more water, reach far forward in the bed of the stream during the dryer parts of the year.

Bars. In the very bottom of the valley, the lowest flats, but a few inches above the water level, are found at all parts of the channel, but generally have their greatest development on the opposite side of the cut bank. They are simply the temporary shoal of high water, and represent the momentary weakening of the currents that carried the materials. They are resting stages of the sands on their way to a more permanent abode in the Gulf of Mexico. In shape these bars are most interesting. The longer ones stretch for a mile or two down the stream, either unbroken or cut into many islands by the network of narrow streams that flow diagonally across them. A series of these longer bars, crossed and recrossed by the stream, may extend for miles along the channel in low water. Other flats are fan-shaped, and vary in form with the strength of the current. Still other bars, crescent in form, hem in the current at every curve of the stream; these will in time be covered with cottonwoods and join the rank of river terraces.

So abundant are the fine sands of the valley that the stream at low water is often so obstructed for many miles at a stretch that it is virtually cut into a series of long, shallow basins connected with each other by short rapids where the water is but a few inches deep. So quiet was the water in some of the basins that where the stream was divided by a medial bar it was often difficult to tell which channel led out below at the lower end of the bar a half mile or more down the stream.

Size of the Channel and Depth of Water.—The channel of the river varies greatly in width between high and low water. At high water it is from forty to sixty rods wide, while during the most of the time its wider places, at the fords, are ten to fifteen rods. The depth of water in the channel varies in a general way with the velocity of the current. The reason for this fact is that the bottom of the river is covered with loose, uniformly fine-grained materials, all of which can be readily picked up and carried forward by moderate currents. Increasing the velocity relatively diminishes the load, and more materials will be picked up and the water consequently deepened. A very interesting result of this effect is the unusual deepening of the stream in high water. In periods of low water much of the sediment is laid down over the bottom of the channel uniformly, in many places to a depth of two or three feet. At high water this will be picked up, and while the surface of the river is rising three or

An upland flat in the foreground; a sage flat bounded by the Little Missouri in the rear. Near the ranch of J. C. Morgan, three miles above the mouth of Beaver creek

Level uplands in the vicinity of Beaver creek. Upland surface covered with coarse gravels

four feet the deepening due to the removal of the materials from the bottom nearly doubles the increase in depth due to the rise of the water. This deepening holds for the Missouri, as well as for its smaller sister valley, and the effect produced on the appearance of the current is striking. In both streams in high water the current does not flow smoothly, but, meeting with this great mass of sediment along the bottom of the channel, the current seems to be checked and deflected laterally and upward in its struggle with the sands which persist in tumbling downward toward the bottom, with the result that the surface is thrown into great heaving, whirlpool-like areas which advance continually down the stream. It is as if the current were continually stubbing its toes on the piles of sand at the bottom of the stream, and, after a sprawling somersault, as continuously recovering itself at the surface of the river. It is through this choking of the current by the fine materials that so much sediment is carried forward by the stream, and hence in high water it appears not unlike a stream of mud.

Upper Terraces.—At an elevation of from 150 to 250 feet, benches are found at several different levels, having an area in some places of many square miles. At Medora, these upland benches have flat surfaces and lie at elevations of 140, 160 and 180 feet respectively. Five miles north of Medora, upland flats were observed at levels of 120, 160, 190, 200, 220, 240, 255 and 310 feet above the river level. Above Beaver creek, flats, several in number, were observed above the level of 200 feet. All of the upland flats mentioned above were surfaced with gravels and coarse materials consisting of chert, quartzite and some material of igneous origin. In some cases the depth of such material was several feet. Its presence on the upland levels renders the soil porous, so that it holds the water which falls upon it, enabling it to support an abundant growth of grass by which it resists both water and wind erosion. Good views of these grassy upland benches are shown in plates X and XI.

Tributary Valleys.—The main valley of the river branches little in comparison with those of a humid climate. This again is a characteristic due to aridity; for, while many gulches have been started, there has been too little erosion in the present cycle of the stream to permit many of the gulches to grow into long valleys. The walls of the valley are broken through in many places, however, by ravines and gulches, and by the waters of a

few large creeks. The valleys of these large creeks simply repeat the characteristics of the master stream, even having, along the lower part of their courses wide, flat bottom-lands. Beaver creek valley is nearly as wide as that of the river, and several of the other creeks have valleys a half mile wide for the lower two or three miles of their course. It is likely that these larger creeks represent cutting in more than the present cycle, having originated when the river was working at some former level.

The gulches, ravines and creek valleys greatly dissect the belt of two or three miles on either side of the river, making travel along the uplands bounding the stream absolutely impossible. Roads pass up the longer creeks until an easy ascent can be made to the upland flat, where the trail continues to the head of the next creek valley from which the approach can be made to the river crossing. A trail extends from Medora to the mouth of Beaver creek, following the valley. Below this point trails lead away from the river in the direction of some one of the several trading points — Williston, Dickinson, Fayette or Wibeaux.

BAD LANDS

Distribution.—The bad lands of the Little Missouri country are in every case distributed in close relation to the river or its tributaries, and since the creeks occur irregularly the bad lands are similarly placed. The "brakes," or bad land areas, assume a great variety of shapes, which are also dependent upon the form in which the creeks branch out. Generally the oval type of area is found near the head of creeks, while the lower course is faced with a belt of buttes two or three deep only. Again, very short creeks or draws head but a few hundred yards back from the main stream. The river itself is walled in on both sides, from Medora to the mouth, by buttes ranging from 200 to 600 feet in height. In passing from the floor of the valley to the uplands, either by scaling the steep faces of the buttes, or by making a detour to the rear along one of the short draws, one generally passes out onto a flat upland. Where two creeks with nearly parallel courses, not remotely separated, divide an area between them the bad lands may become very extensive.

Effect of Older Base Levels.—There is another condition that adds greatly to the complexity of these areas described above. The region plainly shows two base levels, and a sug-

View looking up Blacktail creek, three miles south of the mouth of Beaver creek

gestion of a third. The low, mound-like remnants of buttes dotting the plains here and there suggest a former elevation several hundred feet higher than the present level; in fact, portions of these old levels remain. They are represented by small areas only, as for example the Kildeer mountains, and the part of the divide in the vicinity of Fryburg; also the higher buttes that may be seen along the divides. Sentinel Butte is a remnant of a time long past when the areas had a level 600 or 700 feet higher than at present. These remnants of the former base levels are very deeply dissected, and stand out conspicuously above those of the present cycle. It is through a portion of such an area that one passes in riding from Fryburg down to Medora. When a stream or creek, cutting in the present cycle, works back into the field of one of these more ancient bad land masses, the surface becomes far rougher and more complex. This fact, i. e., the carving of buttes and bluffs from so many different levels, is the one that makes the topography so excessively rough in parts of the region. When one has scaled the steep walls of one level, he immediately encounters a more formidable array of still steeper slopes. From the summit of these hills one looks away from the stream in the direction of the divides and sees the same types repeating themselves until lost to view in the distance; while in the direction of the river one level gives way to another until the bare faces of the bluffs, walling in the stream, offer the last sharp descent to the flats in the valley below. Such an area as this may be seen east of Morgan's ranch along the division bounding Black Tail and White Tail creeks (Plate No. XII.), or east of the old Roosevelt lodge, eight miles below Mikkleson; in fact bad lands persist almost contintinuously from Medora to the mouth of Beaver creek on the east side of the river. This seems to be the most extensive bad land area of the region. Bounded on the east by the divide north of Fryburg, which has an elevation of some 500 feet above Medora, this mass of bad lands extends with a width of fifteen to twenty-five miles continuously from the Northern Pacific railroad to Maple creek, about thirty miles to the north; here it breaks away into a strip of rough, rolling upland, bounded on the Little Missouri side by a strip of bad land several miles wide.

Valley of Government Creek.—One point ten miles north of Medora at the head of Government creek presented some striking features. The basin of the creek was approached from the

west by a very sharp descent from the divide between itself and the Little Missouri. From the top of this divide one sees, extending far to the eastward, an oval, ampitheatre-like valley whose general level is from 100 to 150 feet below the rim of buttes in every side. This whole basin-like area was apparently the watershed for Government creek. Near the center of the valley a lone butte lifted its summit to a level with the rim surrounding the valley. From this point one gets a view of the valley and the highland to the east, north, south and west. The low, round, dumpy, red-topped clay buttes of the valley surround the massive butte in the center and continue on to the east, a tumbling sea of irregular forms, gradually rising in elevation until they merge with the plains several miles to the eastward. On the north, one long, continuous ridge bounds the valley. Far to the southwest, Sentinel and Square buttes are still visible, along with another very large butte in the northwest. In this valley, depressed so distinctly below its surroundings, we evidently have erosion forms of a later cycle imposed upon the remnants of an older and higher base level. Not the least striking feature of this valley is the great extent of burned clay. Most of the low buttes are red-topped and often capped with sandstone, which has assumed a jointed, columnar, structure; or, in some cases, it is fused into a conglomerate mass, due to the effect of heat arising from the burning coal beds beneath.

The Effect of Burning Lignite.—The agent that effected this widespread change in the clays and the sandstone is still at work on the area. At the west side of the valley a ten-foot coal seam outcrops at the head of a draw, and a mile further to the east is found burning. The effect of this burning is not only to lower the level over the area burned by the depth of the coal seam, but to loosen and rearrange all the material lying above the seam, by causing it to cave in, and also by fusing a large part of the more fusible material into scoriaceous masses of large size. These jagged, angular masses resist weathering and erosion, and remain in many parts of the area to add greatly to the roughness. The loosening of the material also makes possible an underground seepage along the level of the burned coal, and a further cracking and loosening of the surface from this cause. An acre or more at the edge of the burning coal was thus depressed below its surroundings. The buttes themselves at this point were being rapidly undermined by the burning of the lig-

A large tree of the Laramie forest. Materials of unequal hardness

nite. The great extent of burned clay throughout this whole region leads one to believe that the bad land erosion is aided in no small degree by these fires in the lignite. The burning of these seams of lignite goes on but slowly. The seam above referred to has been burning in this particular place since 1882, and yet but little more than an acre has been consumed. The coal burns slowly for the reason that the process goes on at a greater or less depth below the surface, and consequently in a somewhat smothered condition. Other beds were seen burning under conditions which indicate that but little progress has been made by the fire for several years. The valley above referred to contains from sixty to eighty square miles. If the fires which have burned the larger part of the coal at the present level in the area were burning in only a few points at the same time, the period necessary to cover the valley would certainly be several thousand years. But this period would be short compared with the time that these hills have been subject to the slow process of rain and erosion. Relatively, therefore, the effect of burning coal in reducing the area to the bad land conditions would be a rapid process.

FACTORS IN THE FORMATION OF THE BAD LANDS

The more important factors in the formation of the bad lands and the steep slopes of the valleys are the following:

1. Streams.
2. Torrential rainfall.
3. Vegetation.
4. Burning lignite.
5. Winds.

The conditions under which these factors work are as follows:

1. Arid climate.
2. Materials of rather uniformly fine texture.
3. Horizontally bedded materials.
4. The presence of irregular concretionary forms.

1. *Streams.*—Erosion in the bad lands is associated directly with stream action, as in any other region. Steep slopes can be formed only where ravines and gulches have developed. Slopes and run-off are inseparable. No depressions occur anywhere, except sloughs which are to be associated with the drift, that cannot be traced to the action of the streams. Streams are necessary agents in the removal of material that is washed down

the slopes, and serve to direct the course of the run-off. The first work on all groups of bad lands, then, began at the valley of the master stream, and the future of every gulch can be inferred from the forms seen along the ravines and creeks. Just as surely as the torrential rill is the parent of the creek, so the gulch formed by an afternoon shower is the ancestor of miles of impassible bad lands.

The river is at work all the time, the larger creeks part of the time and the small creeks occasionally, in transporting materials. Heavy showers temporarily overload the streams, but they accomplish their task by continuing to flow long after the showers have passed. Thus the valleys do not fill up and most of the debris of one shower is carried off before the next one occurs. The melting of spring snows supplies much water, but so gradually that the streams during this season are probably receiving less material than they can carry, and load up with materials deposited at other seasons.

2. *Torrential Rainfall and the Streams.*—Meteorogical observations show that not only does most of the rainfall of this region come during the months of May, June and July, but that the characteristic rains are thunder storms; these furnish much rain on small areas during short periods of time. Several times during the trip down the river, five or six distant thunderstorm centers were counted, hanging over restricted areas of the valley. The waters from these showers get rapidly into the stream, as was shown again and again by a raise in the river following immediately on the passing of the storm. Two series of showers occurred on the afternoons of the 21st and 22nd of July, both too far up the stream to give much rain at the point where the party was encamped; but as a result of these two storms the river rose about five feet, filling its channel from side to side with a deep, brown, muddy current that hurried swiftly by, carrying brushwood and all sorts of debris picked up from the flats. Thus it is that most of the run-off, and the work accomplished by it, is concentrated into a very few hours. The steep slopes along the creeks are affected practically only while the storm lasts; the creeks carry much water for a few hours, and the river is swollen for sevaral days after the storm has passed. The river is kept at a more regular flow than the creeks, because showers are more uniformly distributed along its valley.

Bad Land topography near Blacktail creek. Remnant of former base level in the background

This specially irregular rainfall during the summer season is a matter not yet sufficiently recognized in the climatology of the area, and it seems probable that with an annual rainfall of fifteen inches, some parts of the area receive much less some years, and more others, than the average. The result of this peculiar distribution gives the river, with its long valley, a great advantage over any of its shorter tributaries in the work of valley corrasion; and by deepening its valley rapidly with reference to the creeks, steep gradients and consequent rapid cutting are the rule with them during the intermittent rainfall. It is very likely that some of the smaller creeks entirely escape heavy showers some years, and then have several during one year. The effect of this seems to be that the material accumulated in the valley by the more gradual processes of weathering is so distributed that the rapid flow due to torrential rainfall is not able to remove it all at once; but on the other hand, the torrent finding gradients steep and cutting in the loosened material easy, washes out a deep, trench-like valley through the debris. Such trenches, with vertical walls ten to thirty feet high, are very common all along the creek, and the materials are largely such as have slipped down from the steep slopes of the valleys. As a rule the creeks entrench themselves deeply below the surface of the alluvial fans and flats at their mouths. It is the presence of these numerous deep gorges of the lateral tribuaries of the river that makes traveling along the direction of the streams so difficult.

Torrential Rainfall and Erosion of the Slopes.—The lack of vegetation on the steep slopes due to intense sunlight, aridity, winds, and rapid weathering of the surface, and to a certain extent to lack of homogeneity in the rather weak materials, all contribute to make erosion by the occasional heavy downpours of rain extremely effective while the shower lasts. On the other hand, the long intervals between showers, the small amount of seepage, and practically no solution, tends to give an unusual permanency and stability to the bad land forms. Erosion is largely limited to the lines along which the waters are concentrated.

The erosion of the slopes is accomplished almost entirely by the rain that falls directly on them. A part of the rain that falls upon the flat uplands sinks into the parched surface, and the rest is prevented from running off rapidly, except at the very edge of the bluffs, where some of it gets over to increase

the supply of the slopes. It will be well to consider for a moment just what happens as a result of the torrential rainfall on these slopes, simplifying the matter by eliminating for the time being the other factors, such as nature of material and vegetation.

A rainfall of one inch an hour falling upon slopes facing a ravine five rods wide at the top would be concentrated one thousand times at the bottom of the ravine. At any one point in the ravine all the water that falls above must pass, and this flow will take place about as fast as the rain falls. Where this concentration is most intense, there the steepest slopes will be found. Along the lower end of the gullies we have the effects due to the concentration on the adjacent slopes as well as that due to the run-off from points above in the gully. Here a deep, canyon-like trench is found. In walking up this trench toward the head of the gully one will find the finer materials all removed. The way in which a freshet cleans out these valleys shows that the streams at such times are far from being loaded, the competency having been greatly increased by the concentration of the flow of the waters in a short space of time. The result of this rapid flow is to undermine and to cause slumping of the looser talus material of the gulches, thus placing them in the path of the onward moving torrent, by which they are rapidly removed from the bottom of the gulch to the flatter slopes along the creeks.

At the head of the gulches the slopes through 180 degrees tend to meet nearly at a point. The effect of this arrangement of slopes is to greatly intensify the concentration of the swiftly falling waters and to greatly intensify the power of the stream for erosion. Here the slopes will often be very steep. Where two such gulches head opposite each other, the divide between is rapidly cut away, and buttes are thus isolated from the main valley wall. In many places one can travel along the tops of the thin, reduced divides, passing from one butte to another as they crown the ridge, like citadels on a castle wall. The flatness of the upland area, and the lack of seepage resulting from aridity, combine to make the direction toward which the draws head out above very indefinite. They as often head toward the river as otherwise, a fact that contributes roughness to the belt along the river by separating buttes from the main mass of the bluffs. From this manner of cutting in the draws, many buttes

Butte 500 feet high, near Squaw creek. Such buttes are seen continuously along the Little Missouri. The alluvial flat at the base of the butte is being rapidly cut away by the river

Bluffs characteristic of the Little Missouri. The slopes in the center of the field show the contrast in vegetation due to difference in intensity of sunlight

and remnants of buttes line the valleys of the creeks, in some places three orders with reference to size being found. The wider areas of bad lands seem to be due to the frequent interlacing of the heads of gullies of two or more parallel creeks.

Effect of Materials.—The effect of materials of varying hardness in the faces of the slopes is to add greatly to the roughness of the surfaces. See Plate No. XV. The sandstone concretions jut out from the clay beds and endure considerable undermining before they fall. Softer layers of clay weather away very rapidly, giving rise to shelving terraces. Coal forms a weak member of the series since it slakes readily to chips and dust, and has been burned out in many places, thus loosening great quantities of overlaying material. In a few places thin-bedded limestone adds strength to the clays, and heavy beds of a fine-grained sandstone, but slightly cemented, give added variety to the erosion forms. See Plate XVII. The materials, for the most part, however, are clays of various shades of yellow and gray, and the buttes and bad lands formed from them preserve a remarkable uniformity throughout the valley.

3. *Vegetation.* — The effect of vegetation upon topography is worthy of some attention. The region for the most part is covered with some sort of arid land plants, such as grasses, sagebrush and cactus, juniper and cedar in the ravines, and dense forests of poplar along the valleys. The slopes of the buttes and areas along the river are often entirely devoid of vegetation. This, however, is a matter of slope and exposure to sunshine and winds. The south faces of the buttes are bare and for this reason subject to active erosion, while the opposite slope is grass-covered and decidedly more gradual. Plate XVI. brings out this contrast nicely. In some areas, as one looks toward the south, nothing but long grassy slopes are seen, all of comparatively smooth surface; while the view in the opposite direction shows steep, bare faces only. In the short draws along the river, so placed that protection from winds is afforded, elm and ash were found mingled with cottonwoods. The most striking case of wind control was found at the Kildeer mountains. The mountains extend seven or eight miles from north to south, and protect the east side from the drying west and northwest winds. Here there is a heavy growth of burr oak clothing the lower eastern foot-hills in the vicinity of Oakdale. This was the only place in the whole area where an oak was found.

While it appears at present that the topography determines the position of vegetation, if the origin of the relief is considered, it can be shown that vegetation has had no small part in actually determining topographic forms. Figure 2 is a diagrammatic sketch of ravine conditions that were seen repeatedly. In one instance five parallel draws were seen which took on the characteristics shown in this figure. The ravine here represented has an east-west trend, and is about three miles long. The south facing slopes are exposed to the vertical rays of the sun during the long days of summer and so intensely heated that the growth of vegetation is impossible; consequently they are subject to intense erosion. Talus slopes and alluvial fans of rapidly shifting material accumulate in front of the slopes and push the small creek to the south side of the valley. Low buttes, remnants of the upland plain, now degraded at these points, line the base of the north slope, and increase the roughness. Small draws are heading back into the upland, cutting in behind the fluted marginal sections; these in time will stand out by themselves and be reduced to the level of the smaller foot hills seen below.

On the opposite side of the valley the slopes stand at such an angle that they never get the sunlight very directly. Plants take root and bind the soil so that strong erosion is prevented. The slopes are made more gradual, have a more regular surface, and, from the absence of gully cutting, tend to be much more permanent. The rain that falls upon the slopes gets more gradually to the creek, less material is washed from the slopes, and the creek is permanently lodged at this side of the valley. Thus it results that the valley grows in width by losing materials from the north side. The slopes in being cut back approach the divide more rapidly, and for this reason the bluffs and slopes on one side of the creek often have greater elevations than those on the corresponding opposite side. Gulches quite often occur where the banks are unprotected by vegetation, which in turn is due to exposure to wind and intense sunlight. When we consider that the protective effort of vegetation has been exerted throughout the long period during which rains and winds have been degrading these regions, we cannot doubt that plants have played a large part in modifying forms of topography.

4. *Burning Lignite as an Agent of Degradation.*—No extensive bad land areas were seen along the Little Missouri from

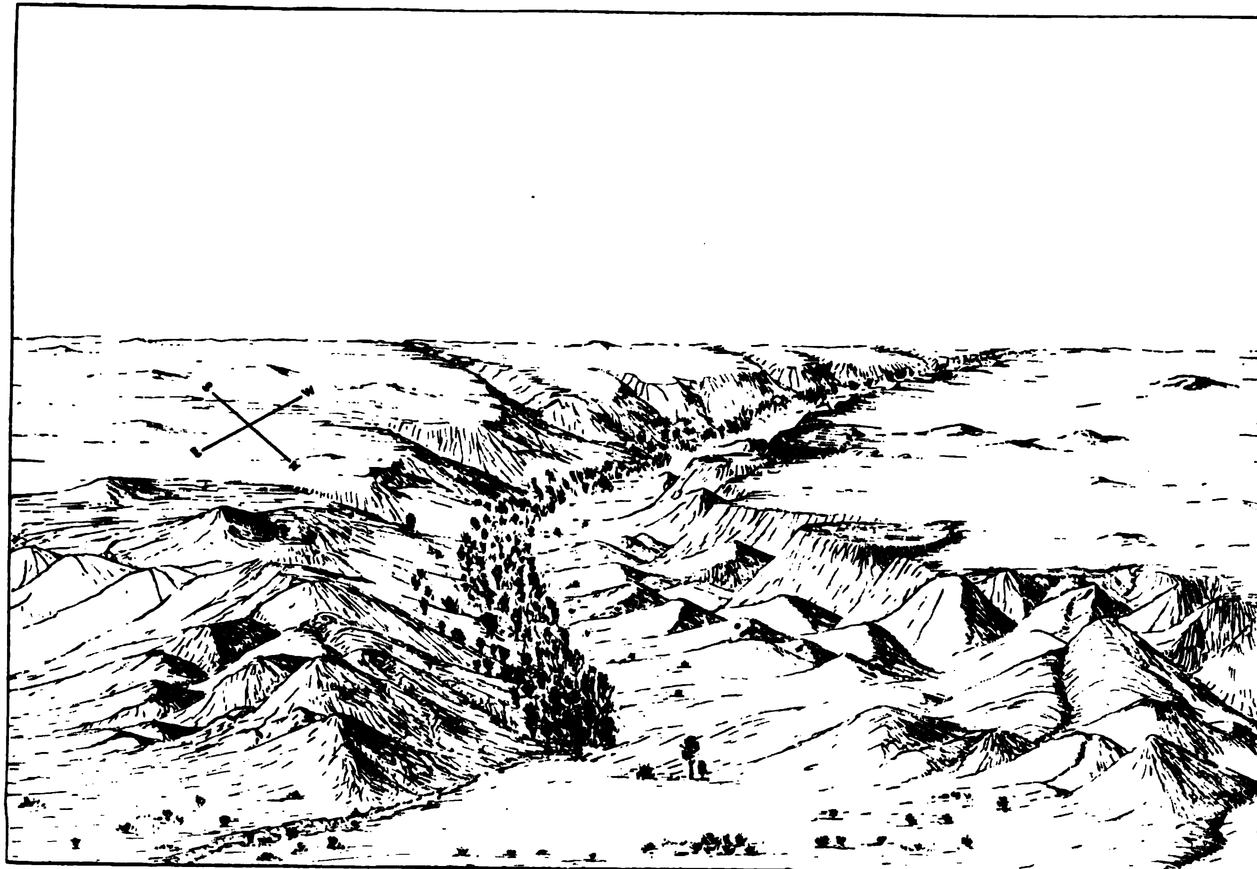


Fig. 2. Effect of vegetation on topography

which red burned clay was absent. There were tens of square miles over which the coal had entirely burned out. Perhaps the most striking area of this character is found ten miles north of Medora, as indicated on the map. But many other places were observed where heavy seams had burned out continuously along miles of the faces of the buttes. Coal was seen burning also in several places, and its effect in loosening materials noted. The burning of the coal goes on with extreme slowness, as measured in years, but rapidly compared with the erosion by rain and wind. One place was seen where the seam was reported to have been burning for twenty-two years; yet the area burned over was only about an acre. Combustion goes on, more or less smothered, under the masses of undermined clay, and since only the face of the seam is exposed the fire is greatly retarded. But even though the agent has worked slowly it has had thousands of years for its task and much has been accomplished. In fact, it seems as if most of the coal has been destroyed in this way. The way this burning aids erosion is principally by undermining large masses of clay, which when once disturbed, become easy prey for the torrential rains. In the cases observed large masses had recently slumped off from the face of the butte which extended one hundred feet above the burning seam. The lignite has the property of holding fire tenaciously, and when once started by prairie fire, or otherwise, the combustion continues until heavy slumps shut off all the air.

Not only is the material loosened, but in most cases the clays above the seam are baked hard to a depth of from ten to sixty feet; and, when gravel and sand lie near the seam, as along the Missouri below Nesson, the materials are fused to a conglomerate mass, which, by its hardness, adds to the irregularity and roughness of the surface. Large areas were seen where the surface above a burned coal seam was covered with a semi-vitreous slag, a material that has been taken for volcanic rock by some who have given the area but casual observation. Masses of this burned clay are so abundant in places that it is used largely for ballast material along the railroads, and probably this will become one of the resources of the area for railroad building, since gravel is rather scarce.

Thus in widening valleys and producing strange and excessively rough lands it seems that the burning of the lignite has had no small effect.

5. *Winds.*—The effect of winds in erosion in the immediate valley of the stream was not strikingly noticeable. Here the walls of the valley furnish a protection from the stronger and more continuous winds. On the uplands, however, where the winds have a clear sweep to the buttes and surfaces unprotected by vegetation, erosion is actively carried on. Small sand dunes were found near concretionary ledges of sandstone. Plate No. XVII shows the effect of rapid cutting away of crossbedded sandstone by wind work. All of the boulders of hard quartzite scattered about the plain in the vicinity of Fayette had smoothly polished surfaces. And the fact that the boulders lie out so openly on the plain may be in part due to the removal of the smaller materials by wind. The effects of winds were far more noticeable in the sandy areas about Dickinson and Gladstone than in the distinctly clay areas.

CONDITIONS THAT DETERMINE THE BAD LAND FORMS

1. *Aridity.*—The effects of aridity have already been considered as a fundamental condition in bringing about the peculiar erosion features. But there are certain other results that should be noticed which are more directly associated with the condition itself. The great excess of evaporation over rainfall has had the effect of lowering ground water level until it lies far below the upland surface. That this is the case is shown by the absence of springs from the cut banks along the river, none being found even though the conditions for springs afforded by the presence of the numerous coal seams at different levels, is very favorable. The springs seen were located far up near the head of the creek valleys, as at the X ranch, at Schafer, and at Oakdale.

As a result of the low ground-water level, the rainfall seemingly never penetrates to it; but, on the contrary, sinks only a few inches below the surface before it evaporates. For this reason seepage is prevented and little slumping goes on except where there is undermining by the stream. It is probably from this cause, together with the impenetrability of the clays, that such steep faces are maintained in the bluffs.

Again, the great dryness of the atmosphere causes the clays to crack up greatly, so that, for a depth of a few inches below the surface they are in condition to absorb water like a sponge, greatly facilitating the dissolution of the faces as well as the more shelving ledges of the buttes. The coal seems also dry out

Cross-bedded sandstone, showing wind erosion. Northwest of Dickinson

and crumble to powder, furnishing weak layers that hasten underming. Further, the aridity keeps the sandy clays in a dry state, and ready to be swept away by the winds, or loosened up so that they are easily transported by the torrential rains.

2. *Uniformity of Materials.*—The fact that the strata consist almost entirely of materials of uniform texture, in a broad way, furnishes the basis for great uniformity of topography. Bad lands and bluffs seen at one part are not unlike those seen at any other in respect to general outlines. The same strata of clays are continuous for miles along the river, and striking seams of yellow clays were observed to be continuous in the valleys of both the Little Missouri and the Missouri river, while the bluffs formed in these beds were remarkably similar. Aside from all these minor differences in form, that disappear with distance, the bad lands at one place seem exactly like those of another, and getting lost in the bad lands is as easy as getting lost in the woods.

The great fineness of most of the materials prevents the penetration of rainfall and compels flow over the surface. Further, the small depth of penetration of water at the surface of the slopes prevents any great effects from freezing and thawing. Plants also do not readily get a foothold in such surfaces. The effect is to decrease the rate of erosion.

3. *Horizontality of Bedding.*—The fact that the beds are horizontal removes the tendency to weakness along bedding planes. Slips that would be common with tilted strata seem for the most part largely absent here. The presence of these horizontal beds over wide areas tends to make valley erosion uniform with respect to slope. The effect of the plants in maintaining slopes and thus producing regularity has been mentioned above.

4. *Concretionary Forms.*—Irregular concretionary forms are very common in many parts of the bad lands. These occur in a great variety of shapes from those of great cylindrical masses of sandstone to small toadstool like forms found occupying the shelves of the buttes in great numbers. Together with the petrified stumps and seams of sandstone, all these masses of greater hardness than the surrounding clays, add much variety to the roughness of bad land forms. These concretions probably, on the whole, tend to retard erosion. The fact that they remain in many places long after the clays about them have been carried away, seems to indicate that they act to check the

work of water on the faces of the buttes about them, though they do break up the continuity of the horizontal bedding.

TOPOGRAPHY OF THE DRIFT AREA

Boundaries.—The area included within the margin of the drift lies largely east of a line running from northwest to southeast through the Kildeer mountains. It coincides practically with the basin of Knife river and its tributaries, and is continuous with the similar topography north of the Missouri and west of the coteau of the prairies. On the east of the Missouri the flatter uplands, rising 300 to 400 feet above river level, merge with the hill belt. On the west side, in the longitude of the Kildeers, the transition to the upland flats, east of the Little Missouri, is gradually passing through a marginal zone where bad land types and drift covered surfaces blend. In some places the western limit of drift is sharp, but in many others extremely indefinite.

Valleys and Slopes.—Throughout this entire area the valleys seem to be entirely too large to be the work of streams now flowing through them. The lower fifteen miles of the Knife river valley is from two to three miles wide, and this unusual width is maintained far up both Knife river and Spring creek. The area of the valleys as compared with the uplands at the heads of the creeks is also very large. Here the valleys really give way to broad depressions between the low hills. Spring creek, Hans creek, Deep creek, and others, now flow in narrow channels across the flat floor of rather broad valleys.

The slopes from the divides to the stream levels are, as a rule, gradual. This fact tends to greatly increase the apparent width of the valleys, since in some places it is difficult to tell just where the valley ceases and the upland begins. Sharp slopes have been toned down by the passage of the ice. The irregular manner in which these slopes have been planed down gives the valley a decidedly unsymmetrical appearance. Buttes and short series of bad lands that hem in the stream at one point give way to long, gentle slopes at another, which extend gradually down from the divides until they meet near the stream levels. For this reason the valley seems wide at one point and very narrow at another. The older preglacial valleys of these streams were probably as uniform in shape and cross section as that of the present Little Missouri. Plate XIX, together with the cross sections of these

stream valleys (Figure 1), will furnish a better idea of the slope than it is possible to give in words.

Distribution of Rough Lands.—If flat upland once existed here, little of the former surface now remains. A view from any of the higher hills of the valley shows lower hills of greater variety, both in elevation and manner of placement, with rather wide valley spaces intervening. Most of the hills are rounded and have long, gradual slopes that blend with the slopes leading down to the stream. In outline the hills also present great variety. Some are round and conical with broad flat areas between them. Others are long and ridge-like, and represent the greatly modified and reduced preglacial divides. There are all grades and sizes from that of the low mound to the rough bad land brakes that crown the crest of the divides between Knife river and Spring creek. Around the Kildeer mountains there is a series of low, knob-like foot hills, which represent the old buttes at the heads of the ancient creeks.

The Kildeer mountains have been preserved by a heavy cap of of dolomitic limestone from degradation by water, and by their altitude from the effects of the ice. They stand 500 feet above the lower hills about them.

Small, island-like patches of rough bad lands, somewhat reduced in elevation, extend between Fayette and Taylor. These areas, while not covered, are surrounded by drift materials, boulders and gravel, which shows that they were too high to be much affected by the ice or the water flowing from it. In some places steep, unmodified bluffs are found along the streams.

Minor Features of Topography.—Terraces twenty-five to sixty feet high were seen bordering the Knife river below Fayette. In the valley of Deep creek south of Rockspring gravel covered terraces twenty and forty feet high were found. Along the Knife valley below Broncho, three distinct terraces were observed at elevations of twenty, forty and sixty feet above the river. Old terrace levels of a height of thirty to fifty feet, capped with coarse gravels, were seen along the lower part of the Little Missouri valley. Streams have cut their channels down from thirty to sixty feet since these terraces were formed.

Sloughs.—Sloughs are not common in the area. Some are found south of Rockspring and along the divide north of Spring creek. Large hay sloughs are reported to exist on the divide between the Knife and Spring creek. There are extensive areas

east of the Kildeer mountains and along the Knife river above Fayette that have the appearance of old lake beds. In fact a small lake is found, at the present time, northeast of Oakdale.

Drift Forms.—The drift was prevailingly thin, and few places were found where the topography was entirely determined by it. North of Halliday, along Hans creek and further east, low, rounded hills covered with several feet of glacial materials were seen. Several knobs of till, consisting of clay, coarse and fine gravel, and boulders, occur along the south bluff of Knife river. This material has the appearance of having been wedged into the old valleys as the ice advanced up the south slope of the river. Boulder trains are numerous, and their presence is usually marked by a slight rise in elevation, as if they had protected the surrounding clays from degradation.

On either side of the Little Missouri near its mouth, many low, rounded hills capped with a coarse, flinty gravel take the place of the steep-faced buttes. They seem to have been in such a position with reference to the ice that they were greatly modified by the outflowing waters which carried the gravels that are now found on the hills.

Dunes.—A large group of dune hills from twenty to sixty feet in height are found on the east side of the Knife river extending for ten miles above Stanton. These forms cover many square miles, as shown on the map, and probably represent wind work on wide flats formed some time during an obstruction of the Missouri below this point. The elevation of the hills is from eighty to one hundred and fifty feet above the level of Knife river.

Origin of the Topographic Forms.—These forms of relief, so strikingly different from those of the Little Missouri, owe their present ontlines to the action of water and ice. The great reduction in elevation is due to both water and ice, as will be explained later. The area was at one time of much simpler configuration, a mixture of rough bad lands with wide stretches of flat upland plain, similar to the region west of it along the Little Missouri. The ice sheet, several hundred feet thick, passed over this more simple preglacial erosion topography, and the long series of consequences due to obstructing creeks, turning rivers out of their courses, deposition of boulders and other drift materials, combined with the flow of water from the melting ice, left the surface in the confused state of relief in which we find it today.

View of Spring Creek valley, near Paulson's ranch

CLIMATE

For the purposes of that part of this report bearing on irrigation, it is necessary that certain elements of climate should be considered. In the report that follows, the data have been taken from the report of the United States Weather Bureau, from the reports of the North Dakota Experiment Station at Fargo, and from the statements of individuals who have spent some time within the area. Since this discussion of climate is made with reference to the agricultural possibilities of the region, some tables are introduced bearing on the question of crops. The tables of temperature are compiled from the reports of three cities on the border of the area, Miles City, Bismarck and Williston, since no observations are available from the central part of the area.

The aridity of this region, in common with that of all the great plains, is due to the presence of the Rocky Mountain barrier, which intercepts the moisture of the prevailing westerly winds. The variability of the conditions of the weather depends upon the cyclonic storms that pass over the United States in a more or less regular succession the year round. The most striking characteristic of the weather is the extreme temperature range of the year, the record showing, at Medora, a maximum of 114 degrees F. and a minimum of -40 degrees F., or a range of 154 degrees. This approaches the range of temperature for eastern Siberia, 171 degrees, which is the highest of the earth.

Winds.—Next to latitude, the position of an area with reference to prevailing winds is the most important factor in the control of the climate, because winds determine the rainfall. The prevailing direction of the wind for the fall and winter months is northwest, while for the summer it is variable. The directions most likely to be followed by rain are southwest, south and northeast. The area is to some extent affected by the chinook winds from across Montana. These, being warm and dry and continuing for some hours, dry up the snow from the plains, making it possible for cattle to feed out for a large part of the winter.

Temperature.—The region is characterized by high summer temperatures and cold winters with extremely low temperatures during the passage of areas of high pressure. At such times the cold air of the "high," coming from upper altitudes of the atmosphere, settles over the region and drives the mercury in the bulb

down almost to its freezing point. Such extremely low temperatures are only occasional. At Williston, the low reading of -41 degrees was recorded once on 1889; at Miles City, -49 degrees was the record corresponding to that of Williston. At Williston the record shows that a temperature of -20 degrees occurred fifteen times during the three years 1896-9.

The following table shows the extreme maximum and minimum temperatures at Williston, Miles City and Bismarck for 1897:

Month	Williston		Miles City		Bismarck	
	Max.	Min.	Max.	Min.	Max.	Min.
January	38	-32	54	-28	42	-30
February	32	-25	43	-20	33	-25
March	47	-35	53	-26	48	-36
April	90	20	88	28	81	19
May	90	25	92	36	90	28
June	101	32	101	42	95	33
July	98	46	100	45	99	47
August	97	40	100	47	93	43
September	94	30	98	30	102	32
October	93	17	88	22	89	13
November	69	-19	76	-26	72	-15
December	49	26	51	-31	52	-23
Year	101	-35	101	-31	102	-36

With reference to these extremely low temperatures it may be said here that the severity of the cold is greatly mitigated by the prevailing dryness of the air. This point will be considered more at length under the head of relative humidity.

Normal Monthly Temperatures.—While it is important to know what the extremes of temperatures may be, it is perhaps more important, to stock men at least, to know the normal or average temperatures that prevail during the winter months, especially; while to the farmer, the temperatures of the growing season are most important. The following table shows the normal temperatures for Bismarck, Williston and Miles City:

Place	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
Bismarck--av. of 24 yrs	4.5	9.5	22.6	42.1	54.2	63.8	69.5	67.5	57.0	43.8	25.9	14.7	39.6
Williston—av. of 17 yrs	3.9	7.7	23.5	42.6	53.2	63.3	68.5	66.5	55.5	43.2	26.1	13.0	38.9
Miles City—for 1897	14.9	15.2	15.4	47.6	63.5	67.0	72.5	71.7	66 6	49.0	25.2	18.8	44.0

A comparison of the figures of this table with similar data from other places of the north central part of the United States and Canada shows that the winter temperatures of the region are similar to those of St. Paul, north central Minnesota and northern Ontario. For July the comparison shows that the region lies in the same belt as southern Minnesota, central Wisconsin, central Michigan, southern Ontario and New York.

So far as the summers are concerned, the region has a more agreeable temperature than the more humid areas with which it is compared. The figures given for the normal temperature of the summer months should be accompanied by figures to show the daily range and night temperatures for the same period, since the comparatively low normals are due to the relatively cool nights. While the heat of the midday sun in the bad lands is excessive, continuing for weeks together to rise to 90 or 100 degrees, the radiations of the nighttime offset the higher temperatures of the day. The following table shows the mean and extreme daily ranges of temperature for the stations, Bismarck, Miles City and Williston:

Month	Bismarck		Miles City		Williston	
	Mean	Extreme	Mean	Extreme	Mean	Extreme
January	22.5	71	21.1	76	15.6	67
February	23.2	77	22.2	70	23.7	70
March	20 7	83	20.6	89	20.3	71
April	20.9	61	24.3	60	21.7	66
May	23.3	58	24 2	46	20.6	42
June	21.6	54	29.3	57	24.4	52
July	25.6	60	27.2	54	23.9	54
August	28.8	58	30.4	56	27.6	56
September	27.4	71	26.5	62	24.9	64
October	24.6	64	24.3	70	28.0	72
November	29.6	70	14.2	96	14.9	62
December	18.5	69	17.8	66	20.3	74
Year	23.0	126	23.8	123	22.2	122

From the above table it will be seen that while the mean daily ranges of temperature, as shown by monthly averages, are rather high, the extreme ranges are remarkably high for both winter and summer. A night temperature of 45 degrees is not

uncommon along the valleys of the streams during midsummer. The following table shows the afternoon and early morning reading at several places that have similar normal temperatures for summer.

Month	Bismarck, N. D.			St. Paul, Minn.			Detroit Mich.		
	4 p.m.	7 a.m.	Difference	4 p.m.	7 a.m.	Difference	4 p.m.	7 a.m.	Difference
January.........	15.8	5.7	10.1	15.6	6.8	8.8	33.6	26.4	7.2
February	14 6	2.0	12.6	19.2	9.2	10.0	38.0	30.3	7.7
March	32.0	16.9	15.1	33 4	22.2	11.2	47 1	36.5	10.6
April............	50.0	31.1	15.9	52.5	39.4	13.1	60.7	48.5	12.2
May.............	61.5	43.0	18.5	62.6	49.0	13.6	68.3	55.7	12.6
June	71.4	54.7	16 7	74.6	61.0	13.6	81.1	68.2	12.9
July...	79.6	58.6	21.0	79.8	62.4	17.4	83.0	68.7	14.3
August..........	80.7	56.1	24.6	78.1	60.3	17.8	82.8	67.6	15.2
September	71.9	48.4	23.5	72.3	55.2	17.1	78.6	62.5	16.1
October	55.6	35.3	20.3	55.3	41.7	13.6	63.4	47 6	15.8
November	31.5	20.3	11.2	34.0	24.7	9.3	47.0	37.7	9.3
December	22 4	11.7	10.7	25.0	18.3	6.7	41.6	33.5	8.1
Year	48.9	32.2	16.7	50.2	37.5	12.7	60.0	48.6	11.4

A comparison of the columns of difference in the above table shows that average fall in the night temperatures during the summer months at St. Paul is from 70 per cent to 80 per cent, and at Detroit 50 per cent to 70 per cent of that which occurs at Bismarck. These figures, as will be shown later, are significant with reference to the growth of certain crops.

Killing Frosts and Length of Growing Season. — It is important to know the length of the season for growing crops, as determined by the earliest and latest killing frosts. Here the farmer should know not alone the average time of first and last frosts, but the average extreme earliest and latest frost, since it is the time within these limits that he must feel reasonably sure of.

The following table is compiled from observations made by the Weather Bureau at Bismarck, Miles City, Williston and Medora during the years 1896-1901:

Year	Bismarck, N. D.		Medora, N. D.		Miles City, Mont.		Williston, N. D.	
	Latest Frost in Spring	Earliest Frost in Fall	Latest Frost in Spring	Earliest Frost in Fall	Latest Frost in Spring	Earliest Frost in Fall	Latest Frost in Spring	Earliest Frost in Fall
1896-7	May 1	Sept. 10	June 7	Sept. 8	May 15	Sept. 17	April 24	Sept. 10
1897-8	June 7	Sept. 16	June 7	Sept. 18	May 14	Sept. 16	May 14	Oct. 8
1898-9	May 4	Sept. 9	May 3	Sept. 3	May 4	Sept. 10	May 6	Sept. 9
1899-1900	May 13	Sept. 19	June 6	....	May 4	Sept. 28	May 17	Sept. 29
1900-1901	April 18	Sept. 26	May 16	Sept. 17	April 17	Sept. 25	May 6	Sept. 27

The temperature of 26 degrees F. is taken as that for a killing frost.*

From the above table it will be seen that the range between the earliest and latest killing frosts is from April 18th to October 8th. The minimum range is from June 7th to September 3d. Mr. Ladd, of the Agricultural College at Fargo, finds at the experiment station from a record of seven years, that the average latest spring frost is on May 23d, and the average of the earliest fall frosts September 12th. This gives the growing season an average length of 111 days. Given such a length of season of growth, one may be sure of the successful raising of most farm crops. The following table taken from bulletin 52, already referred to, shows the number of days necessary to mature some of the more important crops:

CROP	PERIOD
Wheat	83 to 123 days
Oats	88 to 116 "
Barley	82 to 94 "
Millet	81 to 112 "
Spelt	91 to 92 "
Corn	about 100 "

Wheat should be sown not later than the 29th of May, and oats not later than June 4th.

Rainfall.—The rainfall of this area, in common with that of the rest of the state and of Montana, comes largely in the summer during the growing season, and in connection with migratory areas of low pressure that pass across the United States.

*Bulletin 52, North Dakota Agricultural Experiment Station.

The following tables of rainfall and snow are adapted from the report of the Weather Bureau for 1896, and from the Smithsonian Report on Precipitation in Rain and Snow in the United States, by Charles A. Shott:

Stations	Years of Record	Rainfall and Snow at Places in Western North Dakota															
		Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean	Highest	Lowest	Total May to Sept.
Bismarck	22	0.6	0.6	1.1	2.3	2.5	3.5	2.3	2.0	1.2	1.0	0.8	0.6	18.5	31.0	11.2	10.3
Ft. Buford	29	0.6	0.5	0.6	1.2	2.4	2.8	1.7	1.2	0.8	0.8	0.6	0.6	13.8	23.3	7.3	8.1
Ft. Stevenson- 1867-1874	6	0.52	0.28	1.06	0.85	1.5	1.87	1.2	1.9	0.89	0.83	0.43	0.51	11.48	....	....	6.47
Ft. Totten,—1869-1874	5½	0.82	0.47	1.33	1.32	2.53	3.07	1.68	2.76	1.14	0.48	0.88	0.30	16.78	....	....	10.04
Ft. Totten	21	....	....	....	1.4	2.3	3.7	2.4	2.5	1.	....	....	....	Total 13.3	....	....	10.09

COMPARATIVE TABLE

RAINFALL OF GROWING SEASON IN HUMID REGIONS

Place	Rainfall	
	May to September	Annual
Lansing, Mich.—32	14.2	31.6
Madison, Wis.—27 years	15.1	33.2
Minneapolis, Minn.—37 years	14.7	28.2
Chicago, Ill.—29 years	13.7	34.0
Indianapolis, Ind.—26 years	16.0	42.0

The above table shows that, though much of the rainfall occurs during the four months of the growing season, the quantity will be insufficient for most years. Occasional years will increase this amount by a third or a half, when the quantity will compare favorably with the average rainfall of humid regions for the same period of time. It appears, therefore, that the only way for the farmer to be sure of his crops is to resort to irrigation to supplement the uncertain and irregular rainfall.

It must not be thought, moreover, that the quantity of rainfall in winter is without its significance for the farmer. The fact that but small quantities of rain and snow fall in the winter months is one reason why the region is so dry in summer. For, since too little moisture is furnished to saturate the ground, the ground water level remains permanently far below the surface, and is but slightly affected by the occasional rains. The relatively dry atmosphere, then, quickly catches up the water that falls upon the surface as rain or snow, and, for lack of resource in the ground water, remains permanently far below the saturation point, and hence capable of rapidly evaporating the large quantity that falls in the growing season. The demands of evaporation then are always in excess of supply, and hence a permanently arid condition is produced. There is another feature of the rainfall that must not be overlooked. The large part of the summer supply comes in torrential showers, which from their very nature, furnish but an irregular and patchy distribution of rain. Some parts of the Little Missouri valley may, it is believed, pass whole seasons with but a third or a quarter of the average amount stated in the above tables.

The favorable feature of the small winter precipitation and low relative humidity appears from the fact that the snow

usually comes in small quantities and remains so dry that cattle can feed for a large part of the winter.

In the fact of summer rains the influence of five important factors is seen. These are the following: 1. The cyclonic storm; 2. The migration of the belt of cyclonic storms in latitude; 3. The change of temperature in the area north of the Gulf of Mexico; 4. The Gulf of Mexico; 5. The presence of the Rocky Mountain barrier. It is unnecessary to state the laws of the storms that pass continuously across the North American continent; but the effect of the passage of an area of low pressure is to cause the air to move toward the center of the area from all sides. The directions along which the movement is most marked are, in this part of the United States, southwest, south, southeast, northeast and northwest. The currents from the south come from a region of higher and those from the north from a region of lower temperature than that of the storm center. The mingling of these masses of air of different temperature and humidity leads to precipitation over some part of the area of low pressure. Rain may fall either in steady showers or in thunder storms, often accompanied by hail, the nature of the shower depending upon the season and local conditions. During the passage of one of these areas of low pressure the winds shift in direction due to a change in the relative position of the storm center and the place of observation. The succession of winds is south, southeast, east, northeast, north and northwest if the observer is north of the path of the center of the "low," and south, southwest, west and northwest if the station is south of the center of the "low."

The "low" is followed by a "high" pressure area, which has characteristics quite the opposite to those of the "low." The "high" is marked by winds moving outward from the center of high pressure, clearing, rainless sky, lower relative humidity and a marked decrease in temperature. The "high" is often accompanied by a cold wave, that in this region drives the mercury down from 25 degrees to 40 degrees in the winter.

These storms pass in succession every three or four days, so that the area is under the influence of either a "low" or a "high" almost continuously, and to these conditions the rainfall, as well as frequent changes in temperature, is due.

The belt affected by these storms shifts its position from the central and southern part of the United States to the northern part during the spring and summer.

The effect of this oscillation of the belt of storms, combined with the rise of temperature from winter to summer, is to carry the belt of rainfall progressively farther north during the spring and summer, so that in Texas much of the rain falls in the spring, in Kansas in the late spring and in the Dakotas and Montana in May, June and July. This follows as a natural consequence from the law that precipitation does not take place until the air is cooled below the dew point, and obviously such a cooling would occur much further to the north in summer than in winter.

The Rocky Mountains on the west and southwest of this area form a barrier that intercepts and condenses on its western slopes a large part of the moisture of the air that has succeeded in passing the coast ranges still further west. For this reason the region is semiarid. Thus limited on the west the supply of moisture must come largely from the Gulf of Mexico.

While the rainfall comes mostly in the summer season, due to the conditions stated, the minor amount of precipitation during the rest of the year also comes, in part though less directly, from the gulf, and in part from the evaporation and precipitation of the waters from the adjacent land areas. There is much of this drifting of the moisture of the air, and it has been shown that the rain which falls in Montana, for example, may have been reevaporated and reprecipitated several times on its way from the gulf to the interior.

Snow.—The common practice of winter grazing over much of this area indicates that the snowfall is generally light. In favorable years stock feeds out on the plains all winter. The amount of snowfall varies from a few inches to two feet. It usually covers the ground for four or five months, or from sixty-five to 160 days and little falls before the first of January. Some snow may fall by the first of October, but this usually passes away quickly and a mild period, called "Indian summer" occurs between October and January. Mr. Pease stated the following as examples of winter condition which he observed during a seven years' residence in the area. "In the winter of 1898-99 there was no snow after the October fall, which soon disappeared, until the second week of January; the weather was mild during this time. In 1899-1900 the spring thaw occurred the first week in March, so that plowing was done and seeding over before the first of April. In 1902-03 there was little snow in the vicinity

of Dickinson before the first of March. In 1899 a three days' blizzard occurred the 4th of May, bringing much snow and causing a great loss of stock. The temperature during this storm was not lower than 22 degrees F."

A comparison with the snowfall of the other parts of the United States shows that the Missouri valley has less snow than areas either east or west of it. In northern Michigan, the snowfall is 130 inches; in St. Louis, twenty inches; in Utah and Montana fifty inches; while the average in the Missouri valley is about thirty inches.

The number of days with precipitation, both rain and snow, is about 100. The greatest number of consecutive days with precipitation is from ten to twenty; the greatest number without precipitation varies from thirty to sixty.

Sunshine and Relative Humidity.—Not the least among the elements of climate are those that add to the pleasure of living within an area. Some of the earliest and highest civilizations grew up within regions characterized by a high percentage of sunshine and low relative humidity, accompanied by aridity and rather high temperatures. Especially is it true that the more arid parts of North America were inhabited long before the appearance of the European, by tribes of Indians whose strength of body and vigor of intellect were surpassed nowhere else in prehistoric America.

Just what the beneficial influence of sunshine on the health of man may be it is difficult to state; but it is generally recognized that those lands with a high per cent of clear, sunny days conduce in some way to a more vigorous expression of the vital forces. It is certain that the combination of the sunshine with low relative humidity has the physiological effect of enlivening and stimulating to activity. According to Pettenkofer and Voit,* an adult man eliminates about 900 grams of water from his skin and lungs daily. Of this amount 450 grams come from his skin alone. A change of even one per cent in the relative humidity of the air causes very perceptible changes in the amount of evaporation from the skin. If the evaporation from the skin is diminished, the amount of urine is increased, and also in many cases the secretions of the intestines, both of which may lead to injurious effects upon the body. Further, the less diluted blood of dry climates acts as a stimulant upon the nervous system, in-

*Hann. Handbook of Climatology.

creasing its functions. If not carried to extremes, it will be seen that this latter effect of increasing the nervous activity would be conducive to the higher mental activity, and hence increased culture. It is when dry climates and extremely moist climates are compared that the beneficial effects are most noticeable. Damp air and increased pressure have the following physiological effect: Nervous depression; quiet sleep; increased elimination of carbon dioxide; slower circulation of the blood. Dry air and decreased pressure have these effects: Nervous excitement; sleeplessness; quickened pulse; a drier skin and decreased temperature.

Here it may be stated that the ordinary changes of the atmospheric pressure, equivalent at most to a change of altitude of a few hundred feet, have very little if any physiological effect. The effect is due then, in the cases mentioned above, to the change in the moisture in the air. When the moisture content of the atmosphere is large, the effect of changes of temperature is much more noticeable than when the air is dry. For this reason the inhabitants of deserts and dry climates endure, without discomfort, great changes in temperature which would be intolerable in moist climates. Von Middendorff* in describing the climate of eastern Siberia, says; "It would be impossible for man, with his nomadic habits of life there, to endure the extreme cold of western Siberia unless he were helped by the dryness of the air. Fur clothing which has become damp during the day through evaporation from the body, is laid inside out on the snow during the night and in the morning it is completely dry."

While we do not forget that to the dryness of the atmosphere of this area can be attributed the absence of forests and vegetative productivity which is the source of wealth in more humid climates, yet to the few who live here the extremes of both winter and summer, as well as the greater variability of temperature, are made much more tolerable.

Records show that from forty to sixty per cent of the midwinter and from sixty-five to seventy per cent of the midsummer days are clear. The degree of sunshine increases toward the last of the summer. It may also be said that the density of the cloud bank on cloudy days cannot be as great as that of

*Quoted by Hann from Thomas: Beitrage zur Allgem. Klimatologie.

more humid areas. The clouds will therefore have less effect upon the radiations from the surface of the earth.

. The relative humidity, upon which cloudiness depends, is on the average seventy per cent. This is the same as that of Chicago during the dryest days, or when the winds are from the west or southwest.

The following table presents a comparison of the relative humidity of several different areas:

TABLE OF RELATIVE HUMIDITY

Place	January —per cent	February —per cent	March —per cent	April —per cent	May —per cent	June —per cent	July —per cent	August —per cent	September —per cent	October —per cent	November —per cent	December —per cent	Year —per cent	No. of Years Observation
Bismarck	78.9	79.0	76.1	70.2	66.7	70.7	66.6	63.3	65.4	71.2	77.8	77.4	71.9	9
Williston	79.6	80.8	75.0	61.2	58.2	63.1	57.7	54.2	57.9	64.1	75.4	76.9	67.1	9
Miles City, Mont	82.0	80.6	75.4	62.4	57.6	57.4	48.2	44.0	58.8	64.2	76.3	78.3	65.0	5
Des Moines, Iowa	77.4	75.4	70.1	64 4	65.8	69.9	66.7	69.0	70.6	67.1	71.2	76.0	70.3	9
Kansas City, Mo	75.8	75.5	71.1	68.0	69.5	71.1	70.8	71.4	71.9	65.7	70.2	74.4	71.3	8
Pueblo, Col	55.5	49.9	43.8	37.6	43.5	3929	47.6	49.4	41.9	43.9	50.0	53.6	46.2	9
Salt Lake City, Utah	73.3	70.7	60.8	49.3	47.3	39.9	37.0	37.4	41.2	52.1	63.0	72.1	53.7	9
Yuma, Arizona	45.4	43.8	43.9	35.1	36.7	34.7	42.8	47.4	44.7	46.2	43.3	51.4	42.9	9

The figures of this table show that this region of North Dakota can scarcely be classed with the extremely arid regions of the southwestern and western United States. Rather, it is intermediate between the humid east, and the dry west, and the term sub-humid properly applies to it.

VEGETATION IN THE REGION

Any extended discussion of agriculture and crops is entirely outside the province of this report; as a supplement to what has already been said of climate and irrigation, however, attention will be called briefly to the geographic factors in the distribution of some of the more important agricultural resources.

Some interesting facts concerning North Dakota have been brought out by Mr. Mark Alfred Carlton in a study which he has made of the climate and agricultural products of Russia.*

Mr. Carlton states that many of our most valued varieties of grain came originally from some part of Russia. The red winter wheat called Turkey wheat, which has been grown in the

*Bulletin No. 23, U. S. Department of Agricultue.

great plains for twenty-five years, came from Crimea. Probably, also, the entire group of Fife wheats came from Russia, for they are similar to the Ghirkas of the Volga region. Furthermore, a series of field experiments with 1,000 varieties of wheat, and 300 of oats, barley, rye and spelt, have been carried on by the agricultural department for four years, and it is found that Russian cereals, especially the wheats, are best adapted to culture on the prairie and northern parts of the United States.

The investigations with respect to soils and climate show a striking parallelism between certain parts of central Russia and western North Dakota. First in respect to soils; there is the same gradation between black, humus prairie soil, through acid, neutral and alkaline soils that appears in the prairie of the west; there is also a similar combination in the soil of salts which are useful for plant growth. It is quite likely, although no test has been made, that the soils of the river valleys have chemical and physical characteristics that would make them compare favorably with the "black earth" region of Russia.

The climatic parallel is even more striking. In the greater portion of the two regions the winters are long and severe, while the summers, though short, are intensely hot. Other noteworthy features of the climate are, (1) the great number of clear days in the year, (2) the extreme amount of precipitation during two or three months of summer as compared with that of the remainder of the year, (3) the character of this precipitation, falling in quick thunderstorms, as a rule, with very few days of mist or fog, (4) the excessive heat of midsummer, following intensely cold winters, as already mentioned, and (5) the comparatively light snowfall." These characteristics of climate seem to be more pronounced in Russia than in the area under consideration. It is for this reason that Russian crops seem even better adapted to these northern, semiarid parts of the United States, than to their native habitat.

At Samara, near the heart of the Volga country, the rainfall is 15.6 inches, which, it will be seen is about the same as that of the Little Missouri basin. The normal temperature of Samara, 39.3 degrees F., is slightly less than that of Bismarck, while the July normal is 1.1 degrees higher than at the same place.

Botanical investigations have shown that plants subject to the above mentioned characteristics of climate are constituted differently than plants of the humid region. Such plants have

adaptations that enable them to resist, to a certain extent, the evaporating power of hot, dry climates. The cereals grown for centuries in Russia very naturally thrive here. As an example of what is possible in this state, certain examples of the growth of grain in Russia may be stated. The Perm and Vyatka areas having a climate as dry as that of western North Dakota, have stood two years at the head of Russia districts in growing oats. Samara stands forth as a spring wheat district.

Several of these varieties of wheat, oats and rye are well adapted to the valley lands of North Dakota. In their native habitats there is a considerably larger rainfall during the growing season than here, but the deficiency could easily be made up by irrigation. The principal thing to be noticed about these Russian grains is that they are adapted to a short and cool growing season. Many have already been introduced, and others doubtless will be.

It may be interesting to note here that a colony of Russian Germans have settled in the vicinity of Mannhaven, where, by practicing methods of farming learned in their fatherland, they have been successfully tilling the upland soils for years. Good wheat, oats and potatoes, with all sorts of garden stuff, were seen growing on these seemingly arid upland flats, and potatoes were purchased in this region the last of July as good as could be grown in an Illinois garden.

Forage Crops.—Experiments with various forage crops at Brookings, South Dakota, have brought out some interesting facts. The selection of forage crops will become a matter of some importance when the flats of the river have been devoted to the raising of fodder. The possibility of a definite yield of provender for winter feeding is one of the best reasons for adopting irrigation. The following record of crops raised at Brookings suggests the range of possibilities for the valley lands:*

* Bull. 52, U. S. Experiment Station, Brookings, S. D.

RECORD OF CROPS UNDER IRRIGATION

Crop	Date of Sowing	Yield Per Acre	Remarks
Peas	May 18	2.6 tons dry hay	Cut green
Onions	May 4	225 bu. per acre	
Brome grass	....	....	Very successful crop
Oats	May 7	1.68 ton per acre	Cut for fodder
Jerusalem corn	May 11	8.22 tons (green)	Cut for fodder
White Kaffir corn	May 11	18.12 tons (green)	Cut for fodder
Red Kaffir corn	May 11	18 tons (green)	Cut for fodder
Salzer's Superior fodder corn	May 11	25.6 tons (green) 9.2 tons dry	Cut for fodder
Early Adam's fodder corn	May 11	9.6 tons dry	Ears in milk stage by August 10
Alfalfa	May 18	... .	Vigorous growth
Clover	May 18	....	Excellent growth

From the results above tabulated one may readily read the possibilities for the production of forage crops along the flats of the stream already referred to. At the present time the yield of wild hay seldom exceeds a ton per acre, and is generally much less; further, the producing area can be mowed but once in two or three years. Compare this with the capacity of these flats to produce hay and other fodders. The writer has seen between three and four tons of blue joint grass per acre cut from such flats when under irrigation. If the land were plowed and sown to alfalfa or fodder corn, doubtless a much larger yield would reward the farmer. One of these flats well tilled would produce more than several thousand acres of the uplands which are scattered over tens of square miles of territory, reached only by rough roads of steep grade.

In addition to the excellent crops of grain and hay which these flats are adapted to raise, good garden crops are possible. Not only are these possible, but as good garden stuffs as could be grown anywhere in Wisconsin or Michigan were seen during the summer trip. Tomatoes, lettuce, cabbages, potatoes, melons, etc., were ripe by the 5th of August.

Experiments at Brookings on garden truck show the following results.* Tomatoes mature between May 25th and July 22d. Nine varieties of cabbage seed were sown May 20th, and cabbage plants set June 25th. Celery plants, from seeds sown

*Bull. 52. U. S. Experiment Station, Brookings, S. D.

April 9th, were set July 28th. The growth was excellent. "Giant Pearl" furnishes bunches four inches in diameter, averaging thirty inches in length. Hubbard squashes planted June 3d ripened well and averaged eight pounds each. Asparagus gives an excellent growth. Radishes and lettuce produce well.

With reference to the present condition of the grass crop of the plains and its possibilities under a system of irrigation, the following statement taken from Bulletin No. 6 of the Division of Agrostology of the Department of Agriculture, shows the importance of early attention to crops that supplement the grazing industry of this area.

The principal native grasses, Big Blue Stem, Bushy Blue Stem, Switch grass, Western Wheat grass, Western Quack grass, Slender Wheat grass, Fowl Meadow grass, Cord grass, Wild Rye, the Blue Joints and the various species of Stipa, the Gramas, Buffalo grass and Prairie June grass furnish most of the grazing. Blue Joints, Sand grass and Cord grasses furnish the hay in the moister bottom lands.

Overpasturing in time of drouth is killing out most of the grasses here, and unless this practice is abandoned, permanent injury will result to one of the most important natural resources of the west. It is important that every possible effort should be made to preserve the native grasses. They are naturally adapted to the conditions which prevail in this region, and it is quite improbable that introduced forms can be had to take their places satisfactorily, at least for years to come.

"Experience has shown that many of the most valuable native grasses are very much benefited by a judicious application of water. As a rule there is sufficient rainfall to give the grasses a good start in the spring, and if enough water could be had to keep up a strong growth when the dry, hot weather comes on, an abundant forage crop could be assured."

As an illustration of the truth of the above statement it may be said that the writer has seen some three hundred acres of river bottom land at the lower end of the Little Knife river north of the Missouri, under the application of water, producing between two and three tons of Blue Joint grass per acre. The Black Bros., by the expenditure of a few hundred dollars, have turned the arid, sun-burned soil, producing naturally grasses but a few inches in length, into hay fields where grass grows waist high.

In addition to the grasses, "Millet is extensively grown in some farming communities, and such recent introductions as Kaffir corn, Lupines and Arid Sand Vetch seem likely to assume an important place among the forage crops of this region, already so bountifully supplied by nature with the grasses of the field."

Tree Culture—Native Trees.—In the Little Missouri basin there are at the present time several thousand acres of forest land, either on the flats of the river, where cottonwoods hold sway, or in the protected ravines where ash and elm occupy the lower valley and cedars the upper slopes. Many of the bad land buttes have their upper north slope nearly covered with these low growing conifers, and the V-shaped ravines along the river are often crowded with the growth. The cottonwoods are found growing on the lower flats of the stream, and do not seem to be present on the upper sage flats; either they never grew here or they have been killed out by continued drought and the encroachment of the sage brush. It seems rather remarkable that there should be no trace of cottonwoods on the sage flats, which rise but a few feet higher above the river level than the wooded flats. The cottonwood, however, must send its root down to water, and if the distance becomes too great the tree suffers. The slow growing cedar, on the other hand, seems to absorb sufficient moisture from the porous soil about its roots in the ravines. It is not averse to moisture, however, for it usually attains the greatest growth down in the bottom of the draws. None of the trees lift their heads high above the surface of the ground, probably because their growth is cut short by the withering winds. Cedars have been seen three feet in diameter at the base and only fifteen or twenty feet high. A clump of such trees seldom rises above the edge of the protecting crest of the bluff. In very favorable localities cedar attains such a height that poles forty or fifty feet long may be cut. The cottonwoods develop spreading branches when they are free to grow large, and a clump of such trees appears much like elms in form. In places they are found two or three feet in diameter. It is an interesting sight to see the rows of cottonwoods, as they are frequently found, arranged in graded sizes along the river bank. Sometimes they form a fringe of shade along the bank of the stream only; often they form a belt extending along the depressed area in the center of a flat; again they grow large, and

in dense forests occupy the whole flat except where bordered by younger trees on the recently formed banks; or finally the prettiest sight is that where the trees seemed to be arranged along either side of a recently abandoned channel, like shade trees by the road side. (Plate No. XIX.) Where they are too remote from water level the trees are dying out. In some cases fire has killed them off. In many places the space beneath the trees is occupied by a dense growth of shrubs, such as willows, buckbrush, wallberry, buffalo berry and wild roses, which often form almost impenetrable thickets.

The cedars furnish logs for building and for fence posts, for which purpose they are so well adapted that they are sought for by settlers many miles to the east of the area.

Along the east side of the Kildeer mountains there is a large growth of burr oak. Here this tree is preserved entirely by the protection afforded by the mountains. This fact is strikingly attested by the way in which the trees fall off in size toward the south side of the south mountain, where they quickly disappear altogether. They are not found in any case more than a mile to the east of the mountain, and at this distance only where they are protected by the foot hills. Not one lifts its branches above the mountain top, and they are entirely absent from the gap between the mountains and almost entirely lacking from the west side. The richest growth is found just north of Oakdale on the southeast end of South mountain. The presence of these noble trees, so rare in other parts of the Little Missouri valley, lends enchantment to this pretty group of mesas.

Along the valleys of Knife river and Spring creek trees are often entirely wanting. The prevailing growths here are the box elder and the ash, with a few good sized elms along the lower Knife. The box elder grows thick and bushy, with short, often partly prostrate, trunk and spreading branches. Like the cottonwood, this tree occupies the protected places along the stream, often, as it were, crouching down in the old cut-offs of the stream or in an abandoned gulch to avoid the too direct rays of the sun and the drying summer winds. Some of these trees were seen two feet in diameter and rising but twenty or thirty feet above the ground. Because of this stubby, branching growth they make excellent windbreaks, but do not afford much shade.

Flats of the Little Missouri between Morgan's ranch and the mouth of Beaver creek. An old channel appears in the center of the field, cottonwood forests along the stream

There are long reaches on both the Knife and Spring creek where all trees and even shrubs are absent. This is especially true of the upper parts of the streams. Among the larger growths the following well known forms are commonly found, the type varying greatly with moisture conditions:

Wild plum—*Prunus americana.*

Choke cherry—*Prunus virginiana.*

Gooseberry—*Ribes oxycanthoides.*

Missouri gooseberry—*Ribes gracilis Michx.*

Wild red cherry—*Prunus pennsylvanica.*

Sérvice berry—*Amelanchier alnifolia.*

Dogwood family—*Cornus.*

Silver berry—*Elaeagnus argentia* Pursh.

Buffalo berry—*Shepherdia Argentia* Nutt. This is a native fruit producer worthy of careful attention. For jelly making the fruit has few equals. It is currant-like in form and grows in large clusters on a shrub which is found in extensive thickets along the Little Missouri river.

White birch—*Betula.* This is found in a few places, one of which is the vicinity of the Kildeer mountains.

Hazel nut—*Carylus americana*, near Kildeers.

Willows of many varieties—*Salix longfolia* and others. Many of them are sandbinders growing along the river.

Junipers—*Juniperus communis*, a small tree growing in the bad lands. *Juniperus siberia-procumbens*, a small creeping cedar. *Juniperus virginiana*—Red cedar.

Other growths so characteristic of the bad lands as not to be easily overlooked are the Cactus and Artemesia, or sage bush. The sage bush seems to be the growth that succeeds the cottonwood on the flats.

HYDROGRAPHY AND IRRIGATION

Stream Measurements.—A gauging station was established at Medora, May 12, 1903, by F. E. Weymouth of the U. S. Geological Survey. The following figures furnished by Prof. E. F. Chandler, assistant engineer of the State Survey, show approximately the flow of the Little Missouri from the time the station was established up to November 17, 1903:

RECORD OF GAUGING STATION FROM MAY 12 TO NOVEMBER 17, 1903.—MEDORA

Month	Average	Maximum	Minimum
May 12-31	950	2880 May 25	40 May 15
June	240	830 June 26	50 June 20
July	1080	3900 July 5	120 July 21
August	2300	4000 Aug. 6 6100 Aug. 31	900 Aug. 16
September	1240	5550 Sept. 1 2560 Sept. 20	180 Sept. 30
October	70	150 Oct. 1	40 Oct 27
November 1-17	75	100 Nov. 15	60 Nov. 5

Flow given in second feet.

The figures of the above table are not what one would expect from a study of the rainfall records of the area. We find here that while the stream had much more than an average flow for May, the maximum flow occurred during the months of July, August and September. Considering the fact that the rainfall passes rapidly to the channel of the river, it is evident that the heaviest rains came late in the summer for this year. That such

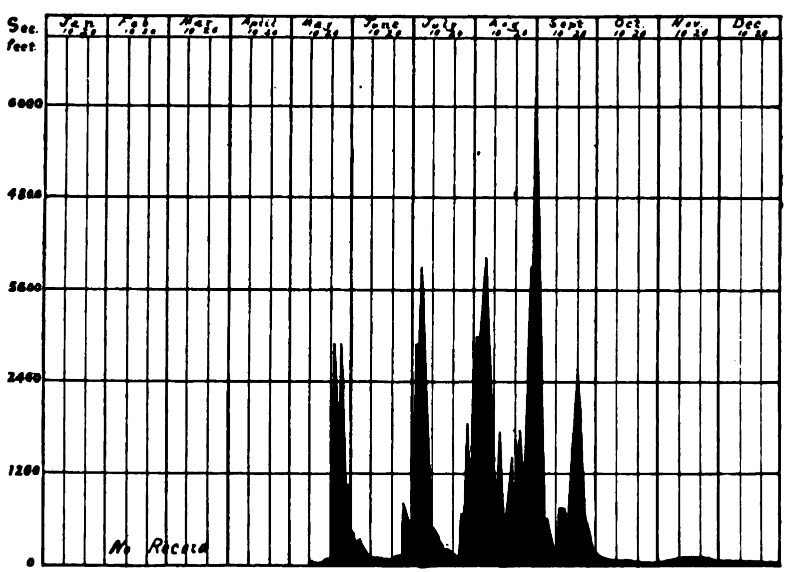


Fig. 3. Discharge of Little Missouri at Medora, 1903

is the case the observations of Mr. Foley, meteorological observer of Medora, show. He reports that the larger part of the

A sage flat

rainfall comes usually in April, May and June, much earlier than in the summer of 1903. Further, that the winter supply of moisture is generally small, so that the river often freezes solid. This is not so remarkable when we recall that the river is but a few inches deep at the rapids during low water.

From the record of the gauging station, as well as from observations made during the summer, it seems probable that there will always be a sufficient supply of water in the Little Missouri for purposes of irrigation along its flats. While the flow of the stream at times becomes very small, the long reaches of quiet water between the rapids, not taken into account in the measurements of stream flow, would be capable of furnishing a large supply, should the actual flow of the stream cease for some considerable part of the summer. Having a depth of from one to ten feet, and being in some cases many acres in extent, these long stretches of standing water in the stream channel are natural reservoirs.

With reference to the use of the stream in irrigation several questions of much more importance than that of stream flow arise. Of first importance is the manner of appropriation. To answer this question it will be necessary to consider the character of the valley, including flats, slopes, nature and number of tributaries and natural fall of the river.

Flats.—An inspection of the relief map accompanying the report will show the relative position of the flats and stream channel. Plates X, XIX and XX show the situation and general elevation of the flats with reference to the bluffs of the river.

The flats are for the most part entirely discontinuous. They lie in the recesses of the valley between successive bluffs which form their upper and lower limits, and represent the area over which the stream has worked during an earlier period in its history. As a rule the flats alternate in position, and so are seldom found facing each other on opposite sides of the river, except along the straighter course of the stream for twenty or thirty miles above Big Gulch creek. The flats vary greatly in size and shape. They are generally triangular, approaching in many instances the shape of sectors of a circle, with the apex extending up draws in the rear. In width from river to bluff these vary from a few rods to a mile. The larger flats are found at the lower end of the creeks, and in these cases extend some distance up the creek valley. Flats of less than forty acres are not con-

sidered in this report. They slope gradually from the lower border of the buttes and bluffs to the line of the river channel where there is always an abrupt drop of from ten to thirty feet to the level of the water in the stream, which is usually found cutting along some portion of the vertical face of the flat.

The soil of these flats is almost altogether alluvial in nature, being the deposit of the stream at an early day or the wash from the adjacent slopes. It is usually of slightly coarser and more sandy material than the undisturbed strata of the bluffs, having a texture which is due to river sorting. The depth of this soil, as observed almost continuously along the stream, is nearly as great as that of the height of the flat above the channel. The surfaces of these flats are usually entirely appropriated by a rank growth of sage, or by low bushes, such as buck brush, wolfberry, and the like. The slope of the surface, both in the direction of the stream and from the bluffs to the river, is very slight; a fact which would be of great advantage in supplying water to the surface.

The creeks entering these flats from the rear cross them in deep, meandering channels, the banks of which support a dense growth of bushes of all kinds. The position of the flats with reference to the creeks is often such as to make it possible by damming, to turn part of the flow of the creek upon the flat. An effort has been made in one or two cases to do this.

The more recently formed flats are not suitable for irrigation; for, while their surfaces are nearer water level, they are very irregular, the soil is sandy, and for the most part they are covered with growths of cottonwood.

Below the mouth of Squaw creek the river cuts more nearly through the center of the valley, thus leaving long narrow flats on either side. In some cases, as below Warren's ranch, the flats are several miles long. In this part of the valley much slumping has taken place recently, which fact renders the surface extremely rough and unfits it for agriculture. There are a few good flats along the stream here, however.

Slopes.—The fall of the stream, on the average, is not more than four feet per mile. In some cases the flow for a mile or more is scarcely perceptible, such stretches being usually terminated by rapids with a fall of from one to three feet. Considering the moderate grade of the stream, the length of the flats and their height above the river, there is no case where the water

could be successfuly diverted by a canal from the stream to the individual flats. In some cases, as already stated, the water might be carried from the creeks to the flat by this method. If dams of sufficient strength could be made to impond a part of the discharge from the creeks, they would become a source of rather a large supply of water.

IRRIGATION

Gravity Methods.—Methods of getting water upon the land vary greatly and depend upon the conditions found upon the individual streams. From the conditions already outlined for the Little Missouri there seems to be but one method of water supply possible for the flats in general, viz., lifting the water to the flats by pumping. The body of flat land is so scattered along the stream, that nowhere could a sufficient area be put under cultivation to make it pay to carry water by tunnel for several miles. Again, the construction and maintenance of an aqueduct of any length along this stream would be a very difficult piece of engineering. Canals running entirely on one side of the river would be subject to the constant undermining of the stream at the cut bluffs. If the canal were carried across the river from flat to flat, as would be necessary on account of the alternate placing of the flats along the river, there would be great difficulty in securing a stable foundation for the midriver supports, since there is no solid foundation to be had anywhere. Other difficulties would be found in securing stone for construction purposes, in seepage and consequent undermining in the fluent clays along the stream, and in the instability of the unconsolidated materials generally.

While diversion of water by canals from the main stream is probably impractical, almost all of the large creeks are so related to the flats at their mouths that the water might be diverted from them to supply a small acreage.

Water Storage.—The flow of the river during the season when water would be most needed, as shown by the record, is from 900 to 1,000 second feet. This is a quantity sufficient to supply all the water needed for 100,000 acres if the water were all used; that is, if none returned to the stream by seepage.

The estimated amount of flat land along the stream is 30,000 to 50,000 acres, or something more than 150 acres per mile. For the quantity of irrigable land it is plain that failure of water

supply is not to be considered at all. The only places where water storage might be of importance is in the creek valleys. In some instances the narrowness of the lower part of these valleys would permit the storage of rather a large body of water, if sluiceways adapted to withstand occasional floods could be invented. The fact that the bottom lands of these parts of the creek valleys are alluvial, leads to ready seepage of water and consequent undermining of dams.

Methods of Lifting Water to the Lands.—There are in general five methods of lifting water to the level of the lands to be farmed:*

1. Pumping by animal power.
2. Pumping by water power.
3. Pumping by windmills.
4. Lifting by elevators or undershot wheels.
5. Pumping by steam power.

The peculiar conditions of this valley seem to warrant the success of any one of these methods, though there is but one of the five that would be applicable and practical everywhere, viz., pumping by steam. The flats lie for the most part not more than twenty-five feet above the river level, and even in time of least flow deep pools from which water could be drawn will be found adjacent to every flat.

There is little need for standing on the question of the sort of pumping that is to be used. There is probably no other valley except that of the Missouri, where, when other methods of irrigation are so entirely impracticable, there is such a fortuitous juxtaposition of flats and fuel. The abundance of lignite in this valley is truly remarkable, and its distribution is of such a character as to render it easily accessible to any flat along the stream. Coal seams at one elevation or another run almost continuously from Medora to the Missouri. Few miles of the river were passed where coal outcrops two or three feet in thickness were not constantly in view; and several seams varying from two to eight feet were followed at times for ten and fifteen miles together. As the abundant fuel has been the life of this western land so far, it is possible also to make it the means of giving more life by employing it to raise water for the thirsty flats. If pumping as a means of irrigation has been found to furnish

*Wilson. Manual of Irrigation Engineering.

water generally more cheaply than gravity sources,* in regions where fuel is scarce, it seems a reasonable thing to expect that the same method could be applied in this valley to great advantage.

There is another consideration that must not be lost sight of. As already stated under the head of climate, a large part of the rainfall may be expected during the growing season, at least several inches even in the most unfavorable years. This fact makes the resort to artificial methods of supply merely a supplement to rainfall and not the whole resource. Without any other than the ordinary rain supply fairly good crops are secured by dry farming, and it seems probable that, were there the inclination, dry farming would be as successful here as in any part of North Dakota. It follows then, that the cost of fuel for pumping being almost nothing, the cost arising from care of an engine would be greatly lessened from the fact that continuous pumping would not be necessary; and at intervals, when other work was not pressing, all hands could be set to work to flood the land in need of water. For this reason it seems practical for both ranching and farming, the one as a complement to the other.

Another advantage that would result from such a method of irrigation is that each man could not merely own his land, but could control absolutely the water supply. There need be no litigation over riparian rights, or priority of use of water, or from difficulties of seepage, matters that so impede irrigation in some of the other states of the west. Few of the flats are larger than the needs of one man require.

Pumping by windmills might be practical for small areas, such as gardens. The difficulty with windmills arises from the fact that the wind cannot be depended upon. Further, with winds blowing steadily, which is far from the case here, the surface of the valley flats is so much below the bluffs—300 to 500 feet—and the valley so narrow, that the full effect of the wind is not felt. Twice only during the summer did the party on the river encounter high winds, and in both cases the wind blew in the direction of the valley. The wind velocity is not more than nine or ten miles an hour at an average on the upland surface, and must be much less in the valley. The capacity of an average windmill in irrigation is from one to

*Wilson, Irrigation Engineering, p. 456.

three acres; but if accompanied by storage reservoirs, from three to five times this amount. There are numerous mills in the west that irrigate from ten to fifteen acres. Wells thirty to 150 feet in depth supplemented by storage tanks furnish the water. These, including mill and tank, cost from $150 to $350.

Lifting by Means of Undershot Waterwheels.—There are some areas along the stream that might be watered by the aid of the undershot wheel. It would, however, be found difficult to maintain a foundation for the support of such a wheel; and further, if it were once placed, the shifting of the channel and undermining of parts of the support would make frequent readjustments necessary.

Lifting by Pump.—This is not the place to enter upon a discussion of the efficiency of different classes of pumps, but it may be of interest to state what their capacity with reference to irrigation may be. In this valley the lift may be taken, on the average, as twenty-five feet and the pump used will brobably be some one of the centrifugal or rotary forms.* The following illustrations show something of the capacity of these pumps:

A centrifugal pump on a farm in southern Arizona, operated by a ten-horse power engine, has a capacity of two-thirds of a second foot per day, or is capable of irrigating three to five acres in a season. A similar pump in the same locality operated by a thirty-five horse power engine handles eleven and one-half acre feet, or about six second feet per day of twenty-four hours. This would irrigate in North Dakota climate, from ninety to 160 acres.

Knife River and Spring Creek Basins.—A gauging station was established at Broncho postoffice by Mr. Weymouth May 29, 1903. Since that time the flow in second feet past that point has been approximately as shown by the following table:

Month	Average	Maximum	Minimum
May 29-31	75	May 25, estimated, between 2,000 and 4,000	
June	30	(June 8) 64	24
July	58	(July 27) 840	(July 25) 16
August	45	(August 29) 311	(August 9) 16
September	62	(September 15) 217	(September 21) 13
October	12	13	11
November	10	13	9

*Wilson. Irrigation Engineering, pp. 469 and 494.

The length of the Knife valley is not far from one hundred miles. While irrigable flats do not border the stream continuously, their extent is between 15,000 and 25,000 acres. If the

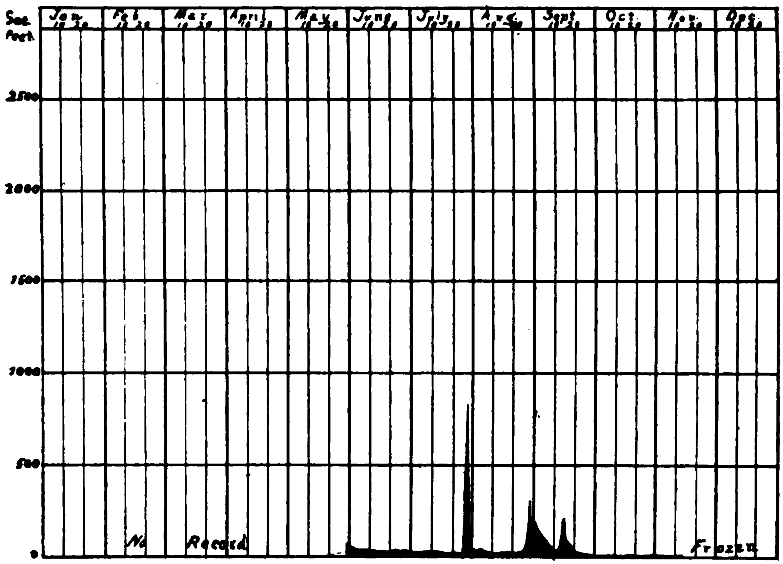


FIG. 4. DISCHARGE OF KNIFE RIVER AT BRONCHO, 1903.

quantity of water allowed per hundred acres is a second foot, it will be seen from the table that the average flow would be far from sufficient to supply the entire area possible for irrigation. Should a part of the flood supply of the summer months, however, be conserved in reservoirs, the supply would be ample. Any system of irrigation that is adopted must be conducted with reference to this fundamental fact. The relative decrease in the supply falls off toward the head of the stream, as above Fayette, where the river, it is understood, often goes dry in the midsummer. Enough water would be retained in the pools toward the middle and lower course to last through the dry season, and the quantity could be easily increased by partially damming the stream at points of diversion. Possibly in this way, for the larger part of the stream, no other sort of reservoir would be necessary. The channel is for the most part canal-like, varying in width from twenty to sixty feet, with a depth of from ten to thirty feet. It meanders through the valley rather widely, so that a single low dam could be constructed, by a few

days work, from the abundant boulders and burned clay found along the valley.

With reference to methods of furnishing water to the land, the conditions, generally speaking, are the same as for the Little Missouri. However, the difficulties that would be encountered on the Little Missouri from bluffs, undermining, etc., in canal building, are absent from this valley; and there is also an abundance of material for ballast, and no serious obstructions along the valley sides. Furthermore there are continuous stretches of flats for twelve miles from the mouth of Crooked creek to J. K. Slack's house in Tp. 142, R. 93, Section 12, and for fifteen miles between Hazen and Stanton, that could be brought under the service of single canals. The size of the flats above mentioned is as follows: From the north of Crooked creek to J. K. Slack's, 2,500 acres; at mouth of Spring creek 1,000 acres; below the mouth of Apple creek at Hazen and Stanton 3,000 to 4,000 acres. There is another stretch of 2,000 acres between Shaffner's ranch and Broncho that might be added to the above list.

The flow of the stream below the mouth of Spring creek must be greatly increased; and it is probable that the added supply from the creek would be sufficient for the flats below this point.

Spring Creek.—Spring creek meanders through flats for a distance of fifty miles. The total amount of irrigable flats is probably 5,000 or 6,000 acres. This is not uniformly distributed, however. For the first twelve miles the flats are extremely broken, small and often of rough surface. From a point a few miles below Halliday the flats begin to widen out, and in places for the next fifteen miles are from a half to three-fourths of a mile wide. Their surface is flat, the soil good, and the elevation above the creek not more than twenty feet. Along the head branches of the creek there are some very large flats which are so near the stream level as to be partly inundated in wet periods.

The flow of Spring creek seems to be much more regular than that of the Little Missouri, and it carries on the average nearly as much water as the Knife. The evenness of flow is due to the drift material covering the slopes of the stream. The supply seems to be sufficient for all the irrigation possible in the valley. Pumping by steam would be as practical on this stream as along the Little Missouri.

Farmers Valley.—Farmers valley is the name given to the rather peculiar valley lying north of Taylor and Richardton, and extending from the head of the Deep creek valley to Hebron, a distance of twenty-five miles. There is no reason why the name should not include the valley of Deep creek, since that is continuous with Farmers valley, and of about the same width and depth. The Little Knife valley, running to the Knife valley north of Richardton also seems to be a part of Farmers valley. The amount of flat land in this series of valleys, between Rock Spring and Shaffner's ranch near the mouth of Little Knife, must be between 8,000 and 12,000 acres. The valley varies in width from one-half to two miles; the flats lie ten or fifteen feet above the creek level, and have rather a smooth surface, and in most places excellent soil. Dry farming is practiced at several points along the valley, both on the flats and adjacent rolling uplands. Deep creek carries enough water, if it is conserved by dams, to supply the land along its portion of the valley; likewise Little Knife has enough water below the junction of the two creeks north of Richardton. With reference to the ten or twelve miles of the valley north of Richardton and Taylor, it is doubtful whether the water supply can be greatly increased over rainfall, since the flats are nearly as wide as the receiving basin of the valley. Near the head of this stretch of flats, southeast of Gunwall's house, there are several large sloughs that might be used for reservoirs. The valley north and west of Hebron was not visited, but from the appearance of the wide flats at the lower portion of that section of Farmers valley it is probable that they continue for some miles at the same width. If the state map is correct, the meandering of streams shown in the eastern part of Farmers valley, and of Little Knife valley, suggest rather flat, open valleys, where water storage by dams would be a simple matter. Further, it seems quite possible that the twenty miles of the valley between Hebron and the Knife river, and a section of the Knife valley, and the twelve miles between Shaffner's and Broncho, might be put under a single system of water supply. There must be 8,000 or 10,000 acres in the flats along this distance of thirty miles. The other tributaries of the Knife river, those on the south side east of the Little Knife, were not seen. It is probable that there are a few good irrigation sites at the lower end of these smaller valleys.

Coal Along Knife Basin.—Coal is just as abundant in this basin as in that of the Little Missouri. Heavy seams are found along the river in both the upper and lower valleys of the stream. Six miles west of Halliday a seam sixteen feet thick of solid coal extends over a large area, lying with its base a few feet below the level of Spring creek. Other seams of from four to eight feet in thickness outcrop at numerous places along the creek below this point. The same abundance of coal was found along Knife river and Farmers valley. The maximum haul of fuel for a steam pumping engine would not be more than a few miles in any case, and, as on the Little Missouri, the engine might in many cases be set up at a coal bank.

OTHER ADVANTAGES OF IRRIGATION

Aside from the aids to irrigation on these streams already mentioned, abundance of coal, moderate elevation of flats above the stream, ease of constructing reservoirs, lack of occasion for expensive litigation over water rights, fertility of the soil, etc., there are other advantages that should be emphasized. Not the least of these are those that pertain to farming generally in the Dakotas. Crops once matured may stand outside after harvest until threshing is done, since the dry air and absence of rain make that a good method of curing grain. This makes the building of large barns unnecessary. Hay keeps well in the stack on account of the dry fall and winter. Stock can be pastured on the uplands far from the growing crops in the valley, and require little attention during the time that the farm crops need care. During the long, dry fall there is much time during which repairs could be made in the irrigation ditches and sluiceways. New ditches could be made and more land brought under cultivation.

But the point of greatest importance in connection with irrigation here is this: The fact that the uplands along the stream are too rough for farming, while they furnish excellent grazing, makes them naturally a supplementary resource for the farmer who owns land adjacent to them in the valley, and for this reason should be reserved accordingly. Along the Little Missouri, especially, is the relation between flats and grazing very close. Here the bluffs divide the belt of flats into sections of from 100 to 300 acres each, distributed at intervals of a half mile or so along the stream. No farming on the uplands in the rear of

these flats is possible. This gives the owner of a flat control of a strip of land a mile or more in width, and extending back to the divide from five to twenty miles away. The strip of grazing land is rarely twice this width, since the flats alternate along the stream. This combination of grazing lands and irrigation possibilities in the area is its most hopeful feature, and it is probable that irrigation will always go hand in hand with stock raising in western North Dakota. The added certainty of a supply of winter provender for stock through irrigation, will make grazing a much surer occupation, and lead to a more systematic use of resources of the higher plains. Though the introduction of farming into the area may multiply the number of head of stock per township, and thus reduce the size of the herd, the added variety due to the new occupation will increase the range of life for man, make the area more populous, bringing in better homes and eventually open up the immense resources of clay and coal in these river valleys. There is no reason why the region from the Montana line on the west to the Missouri on the east should not support a population ten times the present number.

LIGNITE

Distribution.—There is no level as yet determined, where lignite seems to be more abundantly present than at another, and no large area from which it is entirely absent. It seems to be present everywhere, being almost as constant and persistent as the layers of the varicolored clays which form the larger part of the Laramie. The depth of strata observed in the area between the Missouri on the east and the western divide of the Little Missouri is about 1,100 feet, or the difference between the elevation of Bismarck, 1,618 feet, and that at the western part of the state, nearly 2,800 feet. Throughout this depth the materials are mainly light gray or yellow clays, thin beds and irregular concretions of sandstone, with some layers of limestone, concretionary quartzite, locally much fine-grained, stiff, sandy clay, and lastly the lignite seams. The number of thin coal seams in this depth of strata is large, since they occur at all elevations. The number of workable seams, assuming three feet as the lower limit, would be from fifteen to twenty. Large seams were seen at the following levels, approximately:

	FEET
Dickinson	2,380
Medora	2,240
Medora	2,260
Medora	2,300
Burgess'es	2,200
Mikkleson	2,160
Mikkleson	2,200
Beaver creek	2,120
Bolan creek	2,000
Halliday	2,000
Magpie creek	1,900
Near southwest corner of Indian reservation	1,800-1,900

Thick seams have also been found in the vicinity of Sentinel and Square buttes at elevations above 2,800 feet.

Of thin seams, as many as fifteen were counted in a single bluff along the river. These are significant, since they show that conditions for the formation of coal occurred many times in the same area.

REGIONAL DISTRIBUTION

Little Missouri Valley.—Since coal seams of workable thickness were almost constantly in sight throughout the course of the valley for 150 miles, we will mention in this place only those localities where coal was observed to be unusually abundant.

At Medora several good seams are in sight, one of which, near the base of the bluff, is eight feet thick. Four miles north of Medora, opposite Mr. Burgess'es house, an eight-foot seam appears just above low water level, while a three-foot seam lies eighteen feet above. (Plate No. XXI.) A seam ten feet thick was seen in the hills at the head of one of the creeks three miles east of Mr. Burgess'es house. Five miles below this place two seams of three and five feet lie interbedded between strata of sandstone. Beds in similar relations were seen near Roosevelt's old ranch below Mikkleson. Four miles from Young's ranch, ten miles north of Medora, a ten-foot seam of coal was found burning. From the appearance of the burned clay in the area, this seam was at one time very extensive, probably to be correlated with the ten-foot seam seen at Burgess'es.

For several miles above Mikkleson good seams of coal appear in the banks. One of these, a two-foot seam, continues quite persistently at water level for a mile or more. Plate No. XXIII. shows a splendid outcrop of four seams, aggregating about six-

Coal outcrop, eight feet thick. opposite Burgess' ranch, five miles north of Medora

Coal seam sixteen feet thick, two and one-half miles below Mikkleson

teen feet in thickness, over which the covering for a considerable area is not more than fifty feet.

Three miles below Mikkleson a seam sixteen feet thick outcrops in a low butte, half of which has been cut away by erosion. (Plate No. XXII.) The presence of burned clay in the bluffs two miles west of this butte indicates that this seam is very extensive. It is probably the equivalent of the four seams seen south of Mikkleson.

In the vicinity of Read's ranch, besides the seams in the river bluffs, others were seen in the draws extending south from the river; while nearly due west of this point, in the valley of Beaver creek, seven or eight seams, the thickest being three feet, were noticed in several places.

Good seams of coal outcrop in the bluffs opposite Morgan's house, one being ten feet thick. All along the river, both above and below this point, for several miles, two seams, varying in thickness from two to four feet each, were constantly in sight. In fact these two seams were observed continuously for a distance of twelve miles from a point above Read's ranch to near the mouth of Cinnamon creek.

Near the mouth of Bolan creek and again at Redwing creek, a fine outcrop showing a ten-foot seam about a hundred feet above the river level was observed. Other seams of smaller dimensions were also seen here.

Along the course of Squaw creek and in the ravines opposite the mouth of the creek on the east side of the river, a seam thirty-four feet thick was observed. It is probable this is the same that acts as a water-bearing layer to furnish the springs at the X ranch on the head of Squaw creek.

Several miles below Warren's ranch, and almost due west of the Kildeer mountains, several good seams of coal were observed, and small seams at as many as eleven different levels. The seams below this point about the Diamond C crossing are at a considerable elevation above the river. No coal was seen at the Kildeer mountains.

Abundant supplies of coal are reported to exist near Shaffer's ranch on Cherry creek.

A very good seam of coal was encountered in the valley six or seven miles north of the Kildeer mountains. Here slumping has carried great blocks of coal into the river which appeared like black boulders as seen in the distance. A seam about eleven

feet thick outcrops near the mouth of Jim creek and further down opposite Partridge brothers' house, where it had a thickness of eight feet. Just above Manning's old ranch the seam was found burning. Several good seams outcrop along the river below the corner of the Indian reservation.

STRATIGRAPHIC RELATIONS

The coal seams along the Little Missouri lie nearly horizontal, and are for the most part bedded between sandy clays. Sandstone occurs both above and below the coal at several outcrops. The contacts between the coal and the beds above and below are generally sharp. The clays are slightly discolored at some points below the coal by the remains of roots, and in one place a stump was seen rooted in the clay beneath the coal. At several points the coal graded off above and below to carbonaceous shale which, in places, was several feet thick. Now and then several seams merged into one heavier seam, but generally the thickness of the seams remained quite uniform over great distances. Frequently considerable quantities of petrified material occurred where it had weathered out at the upper surface of the coal. Stumps and logs that had fallen from them were often found at the coal horizons.

The various strata of clay lie nearly horizontal, so that the river channel falls continually lower with respect to particular layers of clay as it extends to the north. The bluffs are from 200-300 feet high at Medora, while north of the Kildeer mountains the level of the upland plain is between 500 and 600 feet above the river level. Due to this persistence in horizontality of the respective layers it is possible to roughly correlate the seams at several different horizons. Thus in the table below six different elevations are given at which considerable quantities of coal were seen.

ELEVATION OF COAL HORIZONS WITH RESPECT TO THE RIVER LEVEL BETWEEN MEDORA AND THE MISSOURI RIVER ALONG THE VALLEY OF THE LITTLE MISSOURI

MEDORA TO BURGESS'ES FIVE MILES

	Location of Outcrop	Thickness of Seam	Elevation of Outcrop with Respect to River Level	Materials Above and Below Coal	Extent of Outcrop	Characteristic Strata at the Coal Horizon	Remarks
(a)	Medora	8 feet	50-60 feet above river		Seven rods		Eight seams of coal reported from this point
	4 miles north of Medora; Burgess'es Ranch	10 feet	225 feet above river	Clay	Two rods		This seam probably represents a horizon above that of the seam at Medora
	(Note—As observed 7 miles north at elevation of 250 feet, the seam was largely burned out.)						
(b)	Burgess'es	1 foot to 5 feet	About 100 feet				Probably the several seams represent the seams at Medora

BEAVER CREEK TO BOLAN.

		Location of Outcrop	Thickness of Seam	Elevation of Outcrop with Respect to River Level	Materials Above and Below Coal	Extent of Outcrop	Characteristic Strata at the Coal Horizon	Remarks
C Probably represents one basin. Distance 12 to 15 miles.	(a)	7 miles west of Read's ranch on Beaver creek, 10 miles above mouth	Aggregate 10 to 12 feet	In cut-banks along creek seen at several points	Four seams separated by clay and sandstone	20 rods and ½ mile	....	A 10 foot seam was reported from this vicinity
	(b)	½ mile north of Read's ranch	3 feet	Lies under sandstone at river level	Sandstone above	Seen at several points for a mile or more	Probably lies 60 feet below the seam (d)	Two thin seams above this, may represent the seams at Read's
	(c)	Opposite Morgan's ranch, 6 to 7 miles below Read's	6 to 8 feet	Lies 20 to 30 feet above river level	Sandy clays above. Clays containing iron sulphide concretions below	4 rods	Clays--150 feet above shell bearing layer	Two other seams below this one, of 2⅛ and 3 feet respectively
	(d)	Just above the mouth of Beaver creek	3 and 4 feet	30 to 40 feet above river level	Sandy clays	One mile	200 feet above much concretionary sandstone; 60 feet above limestone, 2 feet, with fossil leaves	These seams were followed 6 miles down the river

BOLAN TO SQUAW CREEK

D	(a)	14 miles north of Beaver creek near Bolan creek	3 feet 4 feet 5 feet 10 feet	At several levels between 80 feet and 90 feet above the river	Clays, sandy clays	Several rods in each case	Many large fossil stumps at the horizon of the upper seams	The lower seam represents another basin. The upper three probably represents basin C
	(b)	6-7 miles below Bolan creek, Redwing creek	10 feet	100 feet above the river		Several rods		Probably the same as the 10-foot seam at Bolan Creek
	(c)	6-8 miles below Redwing, Squaw creek	Coal 5 feet Shale 4 feet	150 to 200 feet above the river	Sandy clay	Several rods	Much fossil wood at the coal horizon	Seam at same elevation at head of Squaw creek 6 miles to west. Seam runs on at high levels for 10 mi. further north

BEAVER CREEK TO BOLAN.

		Location of Outcrop	Thickness of Seam	Elevation of Outcrop with Respect to River Level	Materials Above and Below Coal	Extent of Outcrop	Characteristic Strata at the Coal Horizon	Remarks
C Probably represents one basin. Distance 12 to 15 miles.	(a)	7 miles west of Read's ranch on Beaver creek, 10 miles above mouth	Aggregate 10 to 12 feet	In cut-banks along creek seen at several points	Four seams separated by clay and sandstone	20 rods and ½ mile	....	A 10 foot seam was reported from this vicinity
	(b)	½ mile north of Read's ranch	3 feet	Lies under sandstone at river level	Sandstone above	Seen at several points for a mile or more	Probably lies 60 feet below the seam (d)	Two thin seams above this, may represent the seams at Read's
	(c)	Opposite Morgan's ranch, 6 to 7 miles below Read's	6 to 8 feet	Lies 20 to 30 feet above river level	Sandy clays above. Clays containing iron sulphide concretions below	4 rods	Clays--150 feet above shell bearing layer	Two other seams below this one, of 2½ and 3 feet respectively
	(d)	Just above the mouth of Beaver creek	3 and 4 feet	30 to 40 feet above river level	Sandy clays	One mile	200 feet above much concretionary sandstone; 60 feet above limestone, 2 feet, with fossil leaves	These seams were followed 6 miles down the river

BOLAN TO SQUAW CREEK

D	(a)	14 miles north of Beaver creek near Bolan creek	3 feet 4 feet 5 feet 10 feet	At several levels between 80 feet and 90 feet above the river	Clays, sandy clays	Several rods in each case	Many large fossil stumps at the horizon of the upper seams	The lower seam represents another basin. The upper three probably represents basin C
	(b)	6-7 miles below Bolan creek, Redwing creek	10 feet	100 feet above the river		Several rods		Probably the same as the 10-foot seam at Bolan Creek
	(c)	6-8 miles below Redwing, Squaw creek	Coal 5 feet Shale 4 feet	150 to 200 feet above the river	Sandy clay	Several rods	Much fossil wood at the coal horizon	Seam at same elevation at head of Squaw creek 6 miles to west. Seam runs on at high levels for 10 mi. further north

		Location of Outcrop	Thickness of Seam	Elevation of Outcrop with Respect to River Level	Materials Above and Below Coal	Extent of Outcrop	Characteristic Strata at the Coal Horizon	Remarks
E Probably one basin. Distance 10–15 miles	(a)	10-12 miles north of Kildeer Mts.	11 feet	Just at river level	Clay	10 rods	....	....
	(b)	Near mouth of Jim Creek	6 feet to 8 feet	At river level	Clay	5 rods	....	....
	(c)	2 miles below Jim Creek	8 feet	At river level	Clay	20 rods	Much petrified wood in slab form above coal	A very handsome outcrop
	(d)	3 miles below [c] at Manning's Ranch	6 feet to 8 feet	20 to 30 feet above river	Very fine firm clay	40 rods	....	This coal seam is burning
	[e]	3 miles below Manning's Ranch	5 feet	40 feet above river	Yellow clay	Several rods	Several other seams in the bluff above this one	Seam probably extends several miles further

We have stated the distances through which especially marked seams are known to extend, but these figures are not to be taken as representing the limits of the seams in a north-south direction, since they undoubtedly extend much farther. Whether the east-west extent is as great as the length of outcrop from north to south it is impossible to say; but, considering the longitudinal trend of the stream, it seems probable that this unknown dimension must be many miles in length.

From the extent of these different seams we conclude that the basins in which the coal was formed were very extensive marshes, having an area of hundreds of square miles in some cases, and lying so flat for long periods of time that a bed of vegetable remains twenty to fifty feet thick was able to accumulate. There were undoubtedly many areas within and on the borders of these marshy lands sufficiently high above the level of the water in the marshes to support a growth of mesophytic plants and forests. As portions of the marsh became dryer at certain seasons the trees would advance upon the territory of the marsh plants, and again with the return of wetter periods these trees would be killed and their trunks fall, later, into the mass of marsh plants to increase the material later to be formed into coal. Such a mutual transgression of the various plants inhabiting the marshy regions would be apt to occur many times while the depth of forty feet or more of coal-forming materials was in process of accumulation, and thus logs as well as smaller vegetation would naturally be found mingled in the coal seams.

We find it difficult to realize that such large flats could exist so long a time, at so many intervals during the long Laramie epoch. But there are several reasons, some of which are worthy of mention, why this was the case. The conditions found in this region, it is believed, prevailed generally throughout an area 1,000 miles in length from north to south and two hundred miles wide from east to west, extending from New Mexico far into Canada, and about equal distances on both sides of what is now the Rocky mountain belt. In this broad inland basin sediment went on accumulating for long intervals of time, but not uniformly over the whole area. Land at many points lay so near the water level that vegetation was able to take root and to grow so abundantly that river sediments were shut out of considerable areas for periods of time sufficient to allow the accumulation of tens of

feet of peat and bog materials. We may suppose that this vegetable matter was accumulated much as it is today in the great cypress swamps or in the glacial lake beds that are found in such large numbers in Michigan, Wisconsin and Minnesota. The dense growth of forests, irregularly distributed over the area, furnished a protection from winds that would otherwise scatter loose sands far and wide, while the smaller vegetation acted as a strainer to keep out the fine material that might drift toward the bogs from movements of water currents. Thus almost pure vegetable material could accumulate, and of such the beds are found to consist today.

The materials found in the Laramie beds ot this area have generally a very fine texture, either clays or sandy clays, such as would accumulate under the influence of weak currents in wide shallow basins. The absence of coarce sands and gravel means either that the river entering the area lacked the turbulence of streams issuing from mountain regions, or that peripheral areas from which the stream gathered this material were low and pretty thoroughly disintegrated. If the land was low and marshy it is probable that the streams had but small velocity as they meandered over the region, and for that reason would not be able to carry large masses of drift logs and vegetation as some have assumed that they might have done, thus becoming agents in the accumulation of vegetable materials to be later buried and converted into lignite. In many cases, also, the areas of vegetable accumulation existed for long periods of time practically uncontaminated with clays.

The surfaces of clay and sand upon which the vegetable deposits were made, would be quite smooth and flat. When the water over these flats became shallow, due either to deposition or to the sinking of the water level, vegetation could rapidly take possession, creeping forward to appropriate areas as rapidly as conditions for plant growth became favorable. As some patches rose a little above the critical level for tree growth, forests would spring up, adding variety to the hitherto flat mass of bog plants. Most, if not all, of these hydrophytic forest trees would send their roots out laterally where they would penetrate the mass of peat formed by the earlier growth of the plants. Like marsh trees today, they would not have a very firm hold on the earth beneath, and would be easily toppled over by strong winds.

The occurrence of seams of coal one above another may be accounted for by periodical sinking of the area containing the coal forming basins. But it is likely another process has been in operation, the effects of which have been added to that of sinking. Bain* has shown that the great decrease in thickness which takes place during the change from peat to coal, the coal having but one-tenth to one-fifteenth of the volume of the peat, gives rise to several striking though natural results. The significant point in his discussion, so far as this report is concerned, is that the gradual subsidence of the area would furnish ideal conditions for the further deposition above, and that the coal basins would tend to perpetuate themselves. Given conditions for the formation of one bed of vegetable matter, when this is covered by a thick layer of sediment, it will surely settle through a depth equal to the difference in the thickness of the bed of vegetable matter and the resulting bed of coal. The settling of this bed of vegetation will go on gradually not only while the bed is still uncovered with sediment but also for a long period after it has been buried. It is evident then that when the surface once more is found near water level, and plants have taken possession, the bog will slowly settle, making it possible, without the necessity for general sinking, for plant remains to go on accumulating under the protection of bog waters. It seems quite probable that where there were such wide areas of marshes this factor of settling must have been very effective in bringing about conditions for the formation of numerous coal seams.

It is probable, also, that the coal was formed in situ by the growth of bog-forming plants much as peat is forming today. Bordering these bogs, and growing on them in many places, were forests of shallow rooting trees, which from time to time were added to the smaller vegetation of the bog. The thin clay seams observed in many of the coal seams may be the result of a rise in the water level as well as of a slightly more rapid rate of sinking rather than of plant accumulation.

Analysis reveals but little difference in the nature of the coals throughout the whole area. This is probably due as much to the impervious nature of the materials as to the lack of any extensive deformation of the region, or to the fact that all the seams are, geologically speaking, of nearly the same age. The difference of a few hundred feet in thickness of covering has had

Journal of Geology, Vol. III., p. 646.

[illegible]

Coal outcrop south of Mikkleson. The four seams aggregate sixteen feet in thickness

4. Five miles west of Wiege's, at the creek crossing, there is a five foot seam of coal thirty feet above the creek, and covered, over a large area, by only twenty feet of alluvium and clay. Considerable lignite has burned out at this horizon.

5. Vicinity of Halliday: (a) Township 145, Range 91, Section 19. Here several seams of coal outcrop at different levels. Below Mr. Olafson's house, on the creek, there are two seams of three to four feet in thickness. The outcrops extend up and down the stream for some distance.

(b) A coal seam five feet in thickness is reported from a point five miles below Mr. Olafson's at the ranch of Stewart and McBain.

(c) At Sam Juel's house, Township 145, Range 92, Section 4, a large peat bog has accumulated above the coal seam, and in the bog are some very large springs. Mr. Juel uses these springs to irrigate his garden.

(d) A mile and a half west of Sam Juel's house there are several good coal outcrops.

(e) Mr. Engbrettson, Township 146, Range 92, Section 25, reports coal at his ranch.

(f) At Anderson's ranch, six miles north of Halliday, there is a seam of coal from which a large spring issues. Mr. Anderson uses this spring to irrigate a garden.

(g) Two miles southwest of Halliday, on the south side of the creek, there are two outcrops of lignite three to five feet thick, over one of which there is little covering.

6. Paulson's ranch, six miles west of Halliday's, contains a very heavy seam of coal which outcrops in two places where solid coal rises about sixteen feet above the bottom of the creek. (See Plate XXIV.) This coal seam extends several miles west of Paulson's as indicated by the burned clay along the margin of the creek valley.

(7) Vicinity of Fayette: In the valley of the Little Knife west of Fayette, coal outcrops in several places. Good springs issue at the level of the coal. No large seams were seen here. At Fayette there is a seam three to four feet thick. Little coal was seen in the Knife valley west of Fayette, but near the head of one of its branches, Township 144, Range 99, Section 34, northwest of Brannen's sheep ranch a seam of four to five feet in thickness outcrops for two rods on the creek.

8. Farmers valley: Outcrops of lignite were observed in the valley northwest of Richardton, and near the head of Deep creek. The seam was not over four feet in thickness.

9. Knife river: Outcrops along the valley of this stream above the mouth of Spring creek are numerous, the following being the most important.

(a) At Rockspring two good seams of lignite outcrop for several rods along the creek, and there is a similar outcrop three miles above Rockspring.

(b) Paulson's ranch, Township 142, Range 93, Section 12: Here a seam of five to six feet in thickness outcrops along the river at water level.

(c) Martin Hanson's ranch. Township 142, Range 92, Section 9: A seam five feet thick lies just at water level.

(d) Crowley's ranch. Township 142, Range 90, Section 8: Several outcrops of coal in this vicinity, the seams having a thickness of three to five feet.

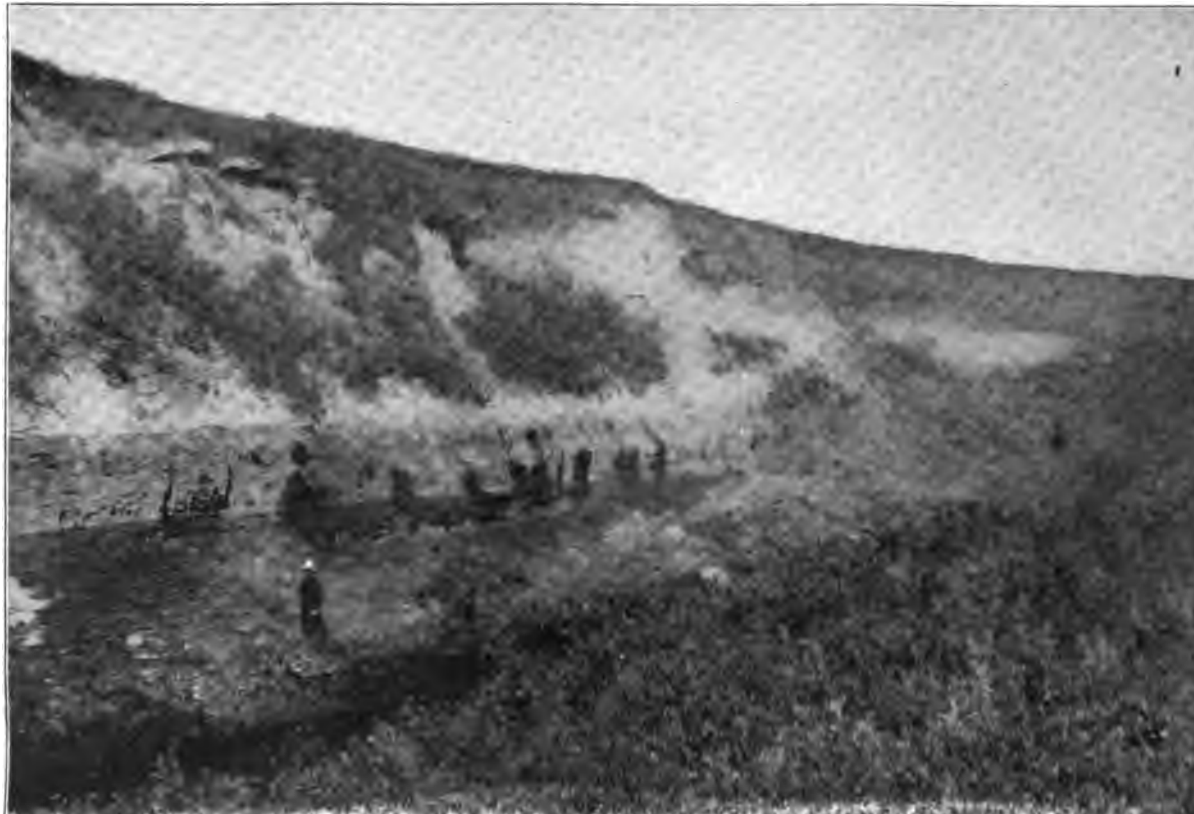
(e) J. Garecht's, five miles below Broncho: Good coal seam reported from this place.

(f) A seam of eight to ten feet was reported from Brady creek four miles south of Hazen.

From the above list of locations it will be seen that while coal is quite generally distributed in the Knife basin, the number of large outcrops is strikingly smaller than along the Little Missouri. This is partly due to a less favorable condition for outcrop, and partly to the drift cover which lies over most of the area. Doubtless much more coal exists here than these outcrops would indicate.

DRIFT PHENOMENA

Margin of the Drift.—The study of the problems of the drift was only incidental to other problems, but the field of work brought the party at several points into contact with the edge of what is called the Kansan drift. The study of the drift is important for the reason that its distribution furnishes an explanation of some of the peculiar features of the region, such as old valleys, springs, the location of the flats, the presence of good soils on the uplands; and, further, it is the cause of the striking contrasts in topography between the little Missouri country and that of Knife river and Spring creek.



Coal seam near Paulson's ranch on Spring creek, ten miles west of Halliday. The seam is sixteen feet thick

The following data furnish the basis for the partial determination of the margin of the drift between Richardton and the boundary line west of the mouth of Bolan creek.

1. Two miles north of the mouth of Beaver creek on the west side of the river, a granite boulder weighing about three pounds was found high up on the face of the bluffs.

2. Two granite boulders weighing sixty and seventy pounds respectively were found in the breaks, west of the river, opposite the mouth of French creek. Also near the same point were two slabs of white dolomite, unlike any rock seen in this vicinity. These were only slightly rounded. To the west of this point up to the crest of the Yellowstone divide for four miles, search was made for more drift, but none was found.

3. Some eight miles north of the point mentioned in (2), just north of the mouth of Bolan creek on the west side of the river, at an elevation of from 200 to 300 feet, much drift material was found. Among the rest may be mentioned the following: large boulders, including white dolomite, hornblende granite, quartzite, and a variety of small materials, all appearing as if they had been dumped here. Also two miles northwest of the mouth of Bolan creek a granite boulder weighing a ton was found.

4. At the head of Squaw creek, just where the valley opens out upon Cherry flats in the ancient valley of the Little Missouri, one and a half miles northwest of the X ranch, much drift was seen. Thirty granite and gneissoid boulders were found in walking over a half mile of the flat. Also there were a number of low, rounded hills on the floor of the valley, gravel covered, and having several granite boulders on their slopes.

Gravel and boulders were reported to be scattered along Cherry valley and the valley of Redwing creek between the head of Squaw creek and Bolan creek.

5. No unquestioned drift was found along the river below Squaw creek until the southwestern corner of the Indian Reservation was reached some ten or twelve miles below the mouth of Cherry creek. From this point on down the Missouri, there was a large quantity of both coarse and fine material. Near the corner of the reservation much coarse gravel appeared in the banks of the stream; and many boulders, so numerous as to make boating in the shallow water difficult, were encountered just below the mouth of Jim creek.

6. About two miles below the old Manning ranch, and fifteen miles east of Oakdale, many large red granite boulders were found, both in the ravines, and on the upland flats, but no fine material was associated with them.

7. Vicinity of the Kildeer mountains. No drift material was found on the west side of the Kildeer mountains, though the entire circuit of the mountains was made by one of the party. Nevertheless the slopes on both the east and west sides of the mountains suggest modification by ice or water action, and small particles of sand and schistose material, found on the tops of the highest buttes on the west side of the mountains, cause one to suspect that ice lay nearby at sufficient elevation to furnish extra marginal drift. Just east of the mountains a dozen granite boulders were found, some of them of great size, together with a large number of a peculiarly hard, flinty quartzites, which were furnished by the area nearby.

From Oakdale eastward the drift increases in quantity, and all the hills are modified in form and reduced in elevation by the action of the ice.

Twelve miles south of the Kildeers a small granite boulder was found on the top of a well rounded hill, and at a point fourteen miles southwest, two limestone boulders similar in character to the limestone that caps the Kildeers.

8. At Fayette postoffice many boulders, both of granite and hard quartzite, are found in the gravel terraces, that were observed extending to the east a distance of eight miles. Here Knife river has cut its channel down fifty-five feet below the top of the terrace that carries the boulders. Along this terrace, in a drive of five miles, we found forty granite boulders, besides thousands of angular boulders of peculiar bluish quartzite of fine texture and extreme, flinty hardness.

No drift material was found west of Fayette until the party reached the head of Knife river near Brannen's sheep ranch, where one large gneissoid boulder was found in the valley about forty feet above the stream level.

The rounded forms of the hills, lying far to the west of the road from Oakdale to Fayette, suggest modification by drift, but there was no time to investigate the matter.

9. The next indications of drift were seen at Dickinson Here, just a mile northwest of the city, by the side of the X trail, a granite boulder was found at an elevation of 250 feet

above the river. Other boulders of granite lay along the railroad track, probably dumped there for construction purposes. Again at the clay pits of the Dickinson Fire and Pressed Brick Company a small granite boulder of thirty pounds weight was found lying on the terrace by the river, along with much gravel that covers the surface of the terraces. This material may have been brought in here by floating ice when the stream was blocked below, in the vivinity of Gladstone, by the lobe of the glacier which reached that vicinity. Similar gravels cover the surface of the terraces along Green river near the road from Dickinson to Gladstone. They consist largely of flints, but contain a few pebbles of igneous rock.

10. Gladstone. Here numerous evidences of drift were found. The area examined extends for three miles southwest of Gladstone, is circular in form, and rather well defined, with a topography sharply contrasted to the more rugged hills to the north and south. Several large pink granite boulders were found in the area, some along the river, and others two hundred feet above. On the west side of the area there is a railroad gravel pit, in which were found, gathered into a pile, twenty-eight boulders, presumably worked out of the gravel. The surface of this area of five or six square miles is rolling, and on the west drops off suddenly to broad flats, where, as reported by Mr. Cryne, no gravel is found.

11. From Gladstone eastward the country rises gradually toward Taylor and Richardton, presenting a rolling surface much flatter than the area west of Gladstone. Just how this area merges with the valley of Heart river south of Knowlton was not ascertained; but to the north of Knowlton the rolling land breaks away into a flat that extends toward the north until it terminates somewhat abruptly in the bluff that overlooks Farmers valley.

Several boulders were noticed in this flat lying along the railroad. It seems not improbable that a lobe of the ice extended along the line of this flat to Gladstone on the west.

12. Boulders were found at Taylor and at Richardton. At the latter place several granite boulders were seen built into a stone fence, and also in the foundation of the grain elevator by the railroad track.

13. Farmers Valley. This valley, lying along the escarpment mentioned in (10), extends from Hebron to the mouth of

Deep creek. It was followed from Richardton to its western extremity. Boulders were found throughout this entire distance lying on the low hills of the valley. Just northwest of Taylor the escarpment retreats to the south for several miles, giving place to a rounded hill of about one-half the height of the escarpment. These hills correspond in height and form to the hills and slopes bounding the north side of the valley. The escarpment extends ten or twelve miles northwest of Taylor and north of Green river, until it merges with the higher and rougher land south of the mouth of Crooked creek. Drift was found on the north side of this escarpment, but not on the south, except at Gladstone and Dickinson, and it seems probable that the drift at these places may be explained by supposing that a lobe of the ice sheet advanced over the escarpment west of Taylor, then moved as far as Gladstone. Here it blocked the streams, thus making it possible for floating ice to carry the gravel and few boulders as far west as Dickinson.

On the basis of the observations above stated we have drawn a boundary of the drift on the map, tentatively, however. This was not the primary work of the party, and the data presented above are given to facilitate the study of those who may take the matter up in detail.

Extra Marginal Drift.—Gravel was found as a veneer on most of the bench land at an elevation of more than two hundred and fifty feet above the Little Missouri, as far south as Medora. At several points between Medora and the mouth of Beaver creek these gravels were found to a depth of two or three feet. This material consists of cherts largely, some of which is shown by fossils to be of Mississippian age, and its source not nearer than the Rocky mountains. Among the cherts are pebbles of quartz prophyry, quartz feldspar rock, diabase, flints, silicified wood, and quartzites. The level uplands over a wide area about the mouth of Beaver creek, are covered with sands that seem to have been assorted, since the grain is coarser than that of sand found in the Laramie clays, and of far more porous texture than the ordinary upland surface where such material is not present. The unusually smooth outlines of the upland flats between Mikkleson and the mouth of Bolan creek leads one to suggest as an hypothesis for the origin of part of the gravels, sands, and smooth uplands, that the Little Missouri was dammed near the mouth of Bolan creek by the Kansan ice sheet; as the result of

this a large lake was formed in the valley above that would allow ice to distribute material over the bed of the lake to the south.. Most of the coarse material, however, probably came from the head of the river in the foot hills of the Rockies, gradually rolled and pushed along to its present position by the current of the stream.

It seems not unlikely, moreover, that the Little Missouri was diverted by the same ice sheet from its former course to the Missouri along the old valley that extends between Bolan creek and the mouth of Tobacco Garden creek, and made to follow instead, the irregular course along the edge of the ice to the north and west of the Kildeers, guided perhaps by the presence of some smaller stream valley already existing in the region.

Farmers Valley.—It seems probable that the edge of the older ice sheet extended along the south slopes of this valley from a point eight to ten miles southwest of Rock Spring, east as far as Richardton, and possibly to Hebron, before it turned south toward the Heart river. The topography along this line, both within and beyond the margin of the ice, shows that the ice did not lie at any great depth over the country. South of Rock Spring there are island-like groups of rough, driftless uplands, rising two hundred feet above surrounding valleys, in which boulders and gravel are abundant. North of Taylor there is an area of several square miles lying in a re-entrant angle of the escarpment itself, and about the same as that of the upland on the opposite side of the valley at the north. The surface of this area has the appearance of having been reformed by ice action. If so the ice filled the valley at least to a depth of two hundred feet, and possibly more than three hundred feet, and advanced on to Gladstone over the escarpment in this vicinity, as before stated. West of this area, for a distance of ten miles or more, the white, bare, clay faces of the escarpment stand out in sharp contrast to the wide valley and its groups of low hills. Deep creek, rising near the escarpment and flowing to the Knife river in the vicinity of Rock Spring, has terraces which in places are gravel covered. Near its head, north of Gunwall's ranch, there are several large sloughs, around which are scattered many boulders. The valley joins with Farmers valley, and this with the valley of Little Knife creek which enters the Knife near Shaffner's ranch, and thus the three valleys form a ring-like depression with the Knife valley as a base.

The explanation of this series of connecting valleys is not easy. It seems possible that the old preglacial valleys of the Little Knife and Deep creek headed near each other in the vicinity of Taylor. Then, during the advance of the ice, the upper waters of the Knife must have turned south for a time, probably through Deep creek valley, so that they would have cut down the divide between the creek and Little Knife; then, later, the flow from the melting glacial ice must have carried off much more material, and thus increased the size of the valley. The cause of the escarpment may be found to be due to hardness of materials, since there is considerable sandstone in the region between Richardton and Dickinson on the west, as was observed in the buttes along the railroad. If this is the case, the advance of the ice to the heads of the old valleys would simply increase the abruptness of the slope on the south, while it rounded off the hills over which it passed on the north.

Quantity of Drift.—The most striking characteristic of the drift covered area is the slight thickness of the veneer over the greater part of the basin of the Knife river. In many places the only element of the drift that remains is a mass of boulders. Till banks were seen in a few places along the south side of the Knife river. At Paulson's house there is a bank of till sixty feet high, containing boulders and gravelly clay. Such banks occur at other points along the Knife below Paulson's both in the bluffs and ridges in the valley, mainly crowded to the south slopes, however. The horizontal beds of Laramie clay, and the unobscured coal seams in the north banks of the river show that little drift remains there if it was ever deposited; while the drift materials on the south bank represent the stuff that was packed by the ice in the old ravines and angles of the banks of the river as it moved up the slopes toward the divide on the south.

A similar distribution of drift prevails along Spring creek. But the thickness of the drift increases toward the north and a depth of several feet covers the hills over considerable areas north of Halliday. Between Halliday and Hans creek the drift becomes abundant enough to have been left in the form of low, rounded hills of a moraine type, between which sloughs and potholes once existed, now mostly drained. East of Halliday there is almost a continuous covering of drift; but two miles west the veneer becomes thin and largely disappears as one passes up Spring creek toward the Kildeer mountains, little remaining to

mark the former presence of ice except the boulders, rounded hills, and reduced slopes.

The quantity of drift when compared with that of the great moraine north of the Missouri, seems very small. It also seems entirely too little to correspond with the great modification of slopes and reduction in elevation that seems to have taken place along the area between the moraine of the Coteau north of Coal Harbor on the Missouri, and the margin of the drift. There is but little material except the boulders that necessarily came from localities far north; probably most of what is now deposited was picked up not far from the Missouri. If the region was as rough previous to the invasion of the ice as its geographic relations at present indicate, the erosion by the ice sheet must have been great. The contrast between the topography of this area and that of the Little Missouri region has already been mentioned, and the roughness of valleys of the streams of the driftless area southwest of the Northern Pacific railroad lead one to suppose that an equally rough area was found here in preglacial days. Further, the presence in a few places in the area of patches of badland brakes, as along the north divide of the Knife river, suggests that bad lands covered a considerable portion of the area. If such rough hills have been degraded, and the sharp bluffs along the streams not only rounded off, but reduced by many tens of feet in elevation, we may well ask what has become of the material.

In attempting a solution of the problem above introduced, several considerations more or less remote from the drift itself are in order. The points to be considered are the following:

1. Climate of the ice age. 2. Direction of the ice advance with reference to that of the streams of the area. 3. Time during which the ice was advancing and retreating. 4. Condition of the area with respect to erosion previous to the ice advance. 5. The nature of the materials both of the area and those brought by the ice. 6. The effect of the ice upon the materials of the area transgressed by it.

1. Climate. The prevailing winds were probably the same during the Kansan time as now. The Gulf stream furnished the moisture to the air which carried northward would reach its dew point rather suddenly on coming in contact with the margin of the ice. Such a sudden cooling would lead to a concentration of rainfall in this region. The seasonal distribution of rainfall

would be about the same as at present, since the controlling factors are the same now as then; this would bring the larger amount of rain during the early summer, which combined with the melting of the ice by the summer heat, would effect a rapid degradation of the clays south of the margin of the ice. This action would continue through the long period while the ice was advancing and retreating through a distance of seventy or eighty miles.

2. Relation of margin of ice to stream direction. Assuming the direction of the ice movement to have been toward the south, the line of advance would form a very acute angle with the preglacial direction of flow of the streams, the result being that they were gradually forced to shift toward the south until their valleys became filled with ice. Then they would overflow at the lowest level. Large lakes would be formed at the head of the stream; and even now such basins actually exist in the vicinity of the Kildeer mountains, along the upper course of Knife river, and Spring creek. The Missouri was gradually forced out of its channel, and the flood of waters from the west must have found its way over this area somewhere, if relative elevations of the time were such as exist today. It seems quite probable that the waters of the Missouri found their way to the southeast by one or all of the old valleys that lie north of the railroad, and possibly by the Heart river. Goodman and Farmers valleys are all much too large to have been made by the streams that now occupy them, and their width may be explained by such an assumption as the above. Such a movement of water would have greatly degraded the soft materials of the area even before the advance of the ice.

3. If the time during which the ice was advancing was as long as the rate of ice movement of modern glaciers would suggest, then the period during which erosion was going on by the agents suggested in (2) was long enough to bring about considerable reduction of the elevation of the area; and to remove much material, as well as to lessen the roughness of the surface. This overflow sought the lower levels of the divides, leaving some of the higher portions untouched. These remain today much as of old. As the melting was in excess of the ice formed during the winters, the quantity of water flowing away in a given length of time was greater than while the ice was advancing, and the erosion was even more rapid for that length of time. The flow from the ice, plus the flow from the streams which gradually

shifted northward back to their old channels, all tended to the degradation of the area.

4. Condition of the area at the time of the ice advance. Even after deducting the effect of leveling by the shifting extra marginal flow of water, there must have remained many small valleys in all parts of the area which became receptacles for part of the material crowded forward beneath the ice. Thus we should expect to find these old valleys entirely obliterated by drift filling, and it is believed that detailed work over the area would discover many such. This amount could be added to the quantity carried off by surface erosion in the attempt to account for the discrepancy between the degredation and the amount of drift present in the area.

5. It is to the nature of the materials that we must turn to find an adequate cause for lack of quantity in the drift. Throughout the area there is no material, aside from coal, that is harder than soft sandstone, and of this little except in the form of concretions, which would in most cases offer less resistance to erosion than tough clay. Much of the clay is sandy, and all of the materials are so fine grained as to be readily carried off by moderate currents of water. The advance of the ice would tend to loosen large masses of the material by pressure, so fitting them for rapid transportation by the streams.

With respect to material from more distant regions, it is probable that there was no great quantity. Of this the boulders frozen into the ice would constitute the larger part, and the remainder would have been gathered largely from adjacent clay uplands on the north, materials as easily handled as those of the area itself.

6. And finally it is necessary to consider what would be the effect of the movement of a great mass of ice several hundred feet thick over an area with the characteristic erosion features and materials of this one. It has been shown that in its movement over surfaces of varying roughness, the ice has little effect on the smoother reaches, while it either removes entirely or greatly reduces the elevation of such features of topography as offer resistance to horizontal movement. From this manner of action, then, the abrupt slopes of the sharp erosion hills of this area must have suffered most as the ice drag passed by. The north bluffs of the east-west stream valleys must have been unable to withstand the pressure due to the weight and crushing

motion of the ice from the north, and born down by the stream, they became easy prey for the water moving along the margin of the ice. Again as the ice pushed its way across the river valley and up the opposite bank, this would likewise give way to erosion by water and the degrading action of the ice, so that a more gentle slope would remain. Such seems to have been the action along Spring creek, and to almost an equal amount on Knife river. Long, gradual slopes today extend from the crests of the divides down to the middle of the channels. Few parts of the region remain unmodified, though some rather rough uplands, with steep and almost impassable bluffs, remain along the crest of the divide of Knife river in the vicinity of Broncho, and farther west near Fayette. The highest of these hills, 300 feet above the river level, are covered with boulders, showing that the ice extended over them. The material carried by the ice, including the boulders, was scattered over the area, the amount carried becoming less and less as the ice grew thinner toward the south. Thousands of boulders are scattered in drifts along the slopes of both streams, many of which lie conspicuous on the hillsides, the finer material deposited with them having been carried away by the streams. In some places more or less gravel has been left with the boulders, as was observed near Rock Spring and along Deep creek. The time since the ice left the area has not been long enough to permit the streams to cut new channels back into the hills of greatly reduced slopes. Neither do the hills and valleys seem to have been much affected by erosion since the ice age. This is due to several causes. The drift veneer forms a loose, porous layer over the surface that takes up much of the rainfall, and either allows it to seep gradually down to the impervious clay to issue as springs, or by the very act of holding the moisture for some time permits much of it to pass away by evaporation. Again the runoff is somewhat delayed by the reduction of slopes, and consequently the erosive action goes on but slowly. Though the actual size of the Knife basin is about one-third that of the Little Missouri the runoff according to measurements in the last season, is but one-seventh to one-tenth that of the stream which flows much of the way through bad lands of steep slope. Again, vegetation has taken a much firmer hold on the long, gentle slopes so that erosion has been impeded on this account.

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The striking changes wrought in the topography by the causes outlined above may be seen by one in looking from the Kildeer mountains, a point from which he can contrast the unmodified bad lands with the greatly reduced relief of the area of the Knife and Spring creek valleys.

TOPOGRAPHIC FEATURES AND GEOLOGICAL FORMATIONS OF NORTH DAKOTA

by

A. G. LEONARD

TOPOGRAPHY

Considered in relation to elevation above sea level the land surface included within the bounds of the state may be regarded as formed of three plains rising one above another. The lowest of these is the broad Red River valley with an elevation of from 800 to 1,000 feet. This is bordered on the west by a higher plain rising from 1,200 to 1,600 feet above the sea, while still farther west and occupying nearly one-half of the state is the elevated highland of the Coteau du Missouri with a surface which rises 1,800 to 2.700 feet and over above sea level. The state thus presents a considerable range of relief, the lowest point, which is in the northeastern corner, being 789 feet above the sea, while the highest yet determined, the summit of Sentinel Butte, is over 3,100 feet.

The remarkably level plain known as the Red River valley stretches along the eastern border of the state and extends from thirty to forty miles west of the river. Near the southern end, at Wahpeton, the valley has an elevation of 965 feet, at Fargo it is 905 feet, at Grand Forks 830 feet and at Pembina, near the Canadian line, 789 feet above sea level, the slope toward the north being about one foot to the mile. It is bounded on either side by higher land rising from 300 to 700 feet above the plain.

Separate names have been applied to different parts of the elevated region bordering the Red River valley on the west and extending far beyond the boundaries of the state, with a length of about 800 miles. The Manitoba escarpment is the eastern edge of the northern portion of this highland, lying mostly in the province of the same name. The slope forming this conspicuous escarpment rises abruptly 300 to 500 feet and over from the lower to the upper plain, the latter stretching far away to the westward. The Pembina Mountains constitute part of this line of prominent wooded bluffs, which extends south into Walsh county, where it gradually fades out. Southward from here almost to the southern boundary of the state the slope leading to the westward stretching highland is gentle and inconspicuous, but the ascent is still 400 to 500 feet. In southeastern Sargent

county and extending into South Dakota is the high plateau-like region widely known as the Coteau des Prairies and forming the southern extension of this same elevated plain. In North Dakota the width of the latter varies from about seventy-five miles at the south to over 200 miles near the Canadian line. To the west this plain is interrupted by a second abrupt slope leading up to the high upland which forms the Coteau du Missouri. Its general surface lies at an elevation of from 500 to 700 feet above the adjoining country to the east, and rises gradually west of the Missouri to a height of nearly 2800 feet above the sea. In Williams and Ward counties the elevation of the upland is from 2250 to about 2400 feet. The eastern edge of the Coteau du Missouri has a general northwest-southeast course across the state, extending diagonally through Ward, northeastern McLean and southwestern Wells counties, then with a more southerly trend crossing western Stutsman, LaMoure and Dickey counties from twenty to thirty miles west of the James river. The Soo railroad from Carrington to Portal, on the international boundary, runs parallel to the edge of the Coteau, and from ten to twenty miles east of it. As previously stated, the plateau of the Coteau du Missouri occupies nearly one-half of the state. On account of its abruptness the slope marking the eastern edge of this plateau is cut at frequent intervals by ravines and gulches. These are perhaps best developed in Ward county, where there are no less than fifty within a distance of seventy miles.

The topography of North Dakota presents greater variety than one might at first imagine. There are the level lacustrine plains of the Red River valley and of the Mouse river region in Bottineau and McHenry counties; the wide stretching, gently rolling to rough drift plain with its innumerable lakes, its comparatively few rivers and imperfect drainage, occupying nearly two-thirds of the state; and the highland area west of the Missouri largely free from drift, with its many buttes, its picturesque bad lands and characteristic erosion topography. These three types of land surface differ widely in origin and present many points of contrast. The vast drift plain, which includes a large portion of the Coteau du Missouri, owes its peculiar features to the deposits made by the continental glacier—its topography is due to the accumulation and deposition of drift. This area is in marked contrast to the erosional topography of the driftless portion

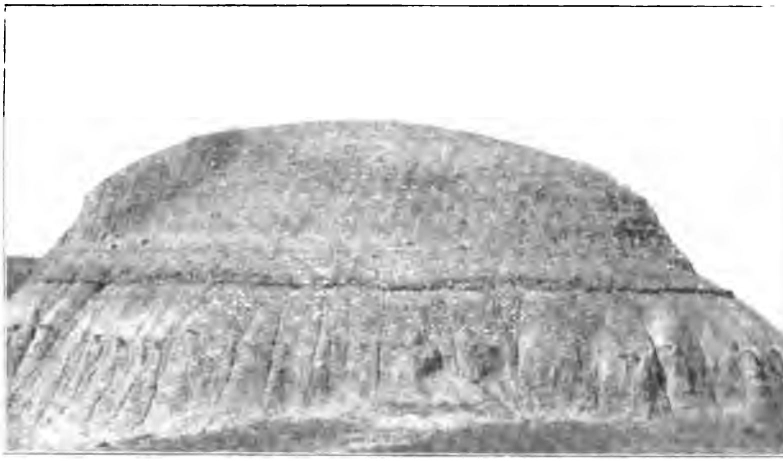

Fig. 1. A dome shaped butte near the base of Sentinel Butte, showing many concretions projecting from the clay slope

Fig. 2. Several low buttes near the station of Sentinel Butte

beyond the Missouri, and to the flat, featureless plain on the east.

The continental ice sheet has been by far the most important factor in moulding the surface features of the state. Its effects are everywhere apparent and unmistakable. Before its advent the area under discussion was probably much more uneven than at present, being an old land surface which had been roughened by the erosion of streams. The continental glacier modified all this and tended to level up the region by wearing down the hills and ridges and filling the valleys with debris. Upon its retreat there was left the heavy mantle of drift, which conceals from view the preglacial surface. It is this drift which forms the rolling, and in places rough plain stretching westward from the Red River valley clear to the Montana line north of the Missouri, and extending fifty miles or more south and west of that river. Wherever the edge of the ice remained stationary for a time a terminal moraine was heaped up.

Eleven such moraines occur in the eastern half of the state and their presence adds much to the roughness of the surface. The Altamont moraine, which is the first or outer one, lying farthest to the west, is described on a succeeding page in connection with the drift. It has a northwest-southeast course across the state, and in Ward county lies along the eastern edge of the Coteau du Missouri. Each moraine consists of a single ridge of drift or belt of ridges and hills varying from a mile or two to fifteen and twenty miles in width. These hilly, morainic belts are often conspicuous topographic features and can be seen from a distance of many miles. The individual hills sometimes rise 100 to 200 feet above the general level of the country, or again they are low and gentle elevations. Many of the hollows and depressions among the hills are occupied by lakes and marshes, which are characteristic of terminal moraines. The lakes are not confined to the morainic areas, however, but are numerous all over the wide-stretching drift plain. They dot the surface by the score and hundred and add beauty and picturesqueness to the landscape. The largest is Devils Lake, which owes its existence to the partial filling up of an old river valley and its tributaries with glacial drift.

The small number of rivers is another noticeable feature of this plain. Aside from the Missouri near its western border, the Mouse, James, and Sheyenne are the only streams of any

importance and even these have few tributaries. There are entire counties without a single river. This scarcity of streams and abundance of lakes indicates a young land surface on which the drainage channels have not yet had time to become thoroughly established and the lakes have not been drained or filled up. Lakes are but ephemeral features at most, since they are either sooner or later drained by the lowering of their outlets or are filled with sediment from inflowing rivers.

Quite a different type of topography is presented by the region lying west of the Missouri, where the surface features are the result largely of erosion. They are due to the action of rain and running water, and not to the accumulation and deposition of glacial debris, which resulted in the formation of the rolling drift plain with its own peculiar topography. In the unglaciated region there are almost no lakes and the area is well supplied with streams which have cut valleys from 100 to 400 feet deep, ramifying in all directions. The large number of buttes rising above the general level of the country is a conspicuous feature here. These are perhaps best seen in the vicinity of the station of Sentinel Butte, where the plain is dotted with many symmetrical, conical shaped hills. Most of the low buttes have an elevation of about 150 feet above the general surface and are seen to be capped with masses of red, burnt clay. The latter was formed by the burning of a coal seam, apparently the eight-foot seam occurring at about the same elevation in Sentinel Butte. The stratum of fused clay has protected the tops of the buttes and given them their uniform height. There are also the high buttes, rising 400 feet and more above the plain at their base, usually flat topped and capped with sandstone. Sentinel, Bullion, Square and Camels Hump buttes may be cited as examples.

By far the most interesting feature of the unglaciated region and in fact the most interesting topographic feature in North Dakota is the famous bad lands. The true bad lands, that is, the very rough areas that are difficult to travel through, are confined to the vicinity of the streams. Back from these five or six miles the land is a rolling plain and is not "bad" in the sense probably meant by the old French term *mauvaises terres* originally applied to the region with reference to its being a land bad for the traveler.

The bad lands are typically developed along the Little Missouri and Medora is located in their midst. The soft Cretaceous

clays and sands described on succeeding pages have been carved by running water into a multitude of steep-sided hills, isolated buttes and an endless variety of fantastic forms. The change is abrupt from the gently rolling plain to the strip of bad lands bordering the river and forming a belt ten to twenty miles wide, within which the effects of erosion are so plainly seen on every hand. This erosion is greatly facilitated by the sparseness of the vegetation, the slopes being almost bare of verdure, and by the softness of the rocks. Though the region is one in which the rainfall is light, every shower is highly effective in washing away the unconsolidated sands and clays. The slopes, the sides of every hill and butte, bear the marks of the last shower. They are grooved with countless tiny channels formed by the little rivulets of water which poured down the slopes. Each rivulet gathered up its load of detritus and carried it on to the main stream. The river has its numerous tributaries and these in turn have their branches which are ever working back into the land. And thus what was formerly a comparatively level plain, similar to that about Dickinson, is now carved into the weird and picturesque bad land topography which is described and figured in all text books of geology.

Beauty and variety is added to the landscape by the diversity of color. The colors are arranged in broad bands along the faces of the bluffs—gray, yellow, black and red of every shade and tint, together with browns and pinks. The banded and many hued bluffs, buttes, domes and pinnacles are a characteristic feature of the bad lands and increase their attractiveness from a scenic point of view.

Turtle Mountains.—This name is applied to the high, rough, plateau-like area occupying a portion of northern Bottineau and Rolette counties and extending across the boundary into Canada. The mountains have a length of over forty miles, a width of about twenty-five miles, and rising as they do 400 to 600 feet above the level plain at their base they are seen for a distance of many miles. This highland is to be considered an outlier or remnant of the Coteau du Missouri, of which it undoubtedly at one time formed a part. The Laramie clays and sands which underlie the Coteau formerly extended east as far as the Turtle mountains, if not farther, and by the erosion of the horizontal beds of that formation this portion of the plateau has been left far beyond the escarpment marking the edge of the main pla-

teau. The intervening depression is the level plain formerly covered by Lake Souris but now traversed by the Mouse river as it flows first south and then swings around to the north and recrosses the line into Canada. The Turtle mountains received a heavy deposit of glacial drift, which has a thickness of 100 feet and more and forms no small part of their height. Over a large part of this highland area the topography is distinctly that of a terminal moraine with its numerous, irregular hills and hollows, the latter occupied by lakes and marshes. The most noticeable features of the region are the great number of lakes, among which Fish lake, about twelve miles north of Bottineau, is the best known, and the exceedingly rough, hilly surface, though there are certain portions which are quite level. Some of the higher points, such as Butte St. Paul, rise 2,300 feet above the sea, and the general elevation of the plateau is from 2,000 to 2,100 feet.

The Turtle mountains are the result of two agencies, water and ice. It was stream erosion which, by carrying away the surrounding strata, first fashioned them from the horizontal Cretacious beds and it was the continental glacier which passed over and modified them, leaving behind the heavy mantle of drift. The peculiar heaped up, hill and hollow topography of this glacial drift gives the mountains their present aspect.

Pembina Mountains.—These are formed by the eastern edge of the highland which borders the Red River valley on the west. In Walsh, Pembina and Cavalier counties the ascent from the lower to the upper plain is abrupt, being from 300 to 400 feet within one or two miles and less, and is marked by a line of wooded bluffs which may be seen from a great distance across the valley. It is this conspicuous escarpment, formed by the outcropping edges of the westward extending horizontal beds of the Cretacious formations, which has received the name of the Pembina mountains. They are the southern continuation of the Manitoba escarpment of the Canadian geologists, which extends north several hundreds of miles along the western border of the Red River valley. The streams tributary to the Red River of the North have eroded their valleys back into the highland and in this part of their course they flow in deep, picturesque gorges. The Pembina river emerges from the escarpment through a steep sided valley 300 to 400 feet deep.

View showing the effect of rain erosion on the Laramie clays and sands. The water channels cut in the slope are clearly shown. Near Williston

River Valleys.—Among the prominent topographic features of the state the river valleys deserve mention. The Missouri flows in a valley from one to several miles in width and 200 to 400 feet deep. It has a broad flood plain, above which lie one or more terraces or flats, and back of these rise the bluffs. In the latter the Laramie beds are often exposed, though the slopes are for the most part gentle, drift covered, and clothed with vegetation. At the big bend near Coal Harbor the river swings against the bluffs along the east side of the valley and these rise abruptly from near the water's edge, while on the opposite side of the valley there is a broad flood plain and the level of the upland is reached by a gradual ascent. Such a difference in the bluffs on opposite sides is common.

The tributaries of the Missouri from the west, the Little Missouri, Cannon Ball, Heart and Knife, have all cut their valleys from 100 to 400 feet below the level of the upland plain and have more or less well developed flood plains a mile or more in width, bordered by terraces.

The James and Sheyenne rivers have eroded their valleys in the drift plain to a depth of 125 to 150 feet and more. Below Jamestown the James river flows in a flat-bottomed valley one-half to a mile wide and with rather abruptly sloping sides.

The valley of the Des Lacs river contains the long, narrow lakes known as the Lower, Middle and Upper Des Lacs, the latter being about twenty-five miles long.

The following list of elevations, taken from Gannett's Dictionary of Altitudes*, shows the altitude above sea level of many railroad stations in North Dakota:

ELEVATION OF RAILROAD STATIONS.

LOCALITY	ELEVATION
Almont	1,920
Alta	1,427
Anamoose	1,620
Antelope	2,411
Arvilla	1,017
Ashley	2,001
Balfour	1,613
Bartlett	1,529
Bathgate	821
Beach	2,756

*Bulletin No. 160, U. S. Geol. Surv.

LOCALITY	ELEVATION
Bear Butte, Turtle Mountain	2,200
Belfield	2,579
Belle Plain	1,270
Berlin	1,470
Berthold	2,082
Berwick	1,482
Bismarck	1,670
Bismarck, Missouri river, low water	1,618
Bismarck, Missouri river, high water	1,638
Bottineau	1,638
Bowbells	1,958
Boynton	1,495
Buffalo	1,202
Buford	1,944
Buford, Fort, Yellowstone river, low water	1,855
Buford, Fort, Yellowstone river, high water	1,875
Burlington	1,590
Butte St. Paul, Turtle Mountain	2,300
Cando	1,488
Canfield	905
Carpio	1,696
Carrington	1,579
Casselton	934
Cathay	1,585
Churchs Ferry	1,458
Cleveland	1,842
Colgate	1,177
Coteau du Missouri	1,800
Crystal Springs	1,792
Cuba	1,352
Curlew	1,956
Dalrymple	922
Dawson	1,748
Des Lacs	1,897
Delamere	1,066
Delta	2,258
Denbigh	1,485
Devils Lake	1,434
Devils Lake station	1,464
Dickinson	2,405
Donnybrook	1,760
Drayton	798
Driscoll	1.871
Eagles Nest	2,098
Edgeley	1,568
Eland	2,436
Eldridge	1,541
Ellendale	1,449

LOCALITY	ELEVATION
Emerado	898
Fairmount	983
Fargo	903
Fessenden	1,610
Fingal	1,277
Forest River	862
Forman	1,249
Fort Yates	1,670
Foxholm	1,657
Fryburg	2,768
Gassman	1,682
Geneva	1,835
Gladstone	2 348
Glenullin	2,070
Grafton	827
Grand Forks	830
Grand Harbor	1,454
Granville	1,503
Haggart	905
Hankinson	1,068
Harvey	1,596
Havana	1,294
Hebron	2,158
Hillsboro	901
Hobart	1,419
Inkster	1,036
Jamestown	1,408
Kenmare	1,799
Kensal	1.541
Knife River	2,188
Knox	1,605
Kulm	1,966
Kurtz	2,025
Lakota	1,514
La Moure	1,307
Langdon	1,610
Larimore	1,134
Leeds	1,514
Leola	1,587
Lisbon	1,091
Little Missouri station	2,266
Lone Tree	1,995
Lucca	1,199
McCanna	1,140
McKenzie	1,698
Magnolia	1,077
Mandan	1,646
Manfred	1,605

LOCALITY	ELEVATION
Manitou	2,275
Mapleton	907
Matteson	1,380
Mayville	978
Medina	1,794
Medora	2,267
Menoken	1,720
Merricourt	1,644
Michigan City	1,517
Milton	1,586
Minot	1,557
Minto	820
Napoleon	1,955
Neche	831
New Salem	2,163
Niagara	1,440
Northwood	1,119
Norwich	1,526
Oakes	1,320
Ojata	858
Oriska	1,270
Park River Junction	1,133
Park River	998
Pembina	789
Pembina Mountain	1,500
Petersburg	1,519
Pleasant Lake station	1,603
Portal	1,954
Ray	2,271
Richardton	2,466
Rolla	1,818
Ross	2,287
Rugby	1,561
Rugby Junction	1,561
St. John	1,945
St. Thomas	840
Sanborn	1,444
Sandoun	1,074
Sawyer	1,525
Scoria	2,482
Sedalia	2,032
Sentinel Butte	2,709
Sheldon	1,080
Sidney	954
Sims	1,962
South Heart	2,482
Spiritwood	1,479
Spring Brook	2,113

LOCALITY	ELEVATION
Stanley	2,252
Steele	1,859
Sterling	1,867
Stump Lake	1,417
Sully Springs	2,575
Sunnyside	1,658
Sweet Brier station	1,806
Tappen	1,762
Taylor	2,488
Thompson	865
Tioga	2,273
Tower	1,172
Towner	1,475
Turtle Mountain	2,150
University	833
Urbana	1,472
Valley City	1,220
Velva	1,511
Voltaire	1,587
Wahpeton	965
Wheatland	993
Wheelock	2,374
White Earth	2,087
Williston	1,854
Willow City	1,471
Wimbledon	1,486
Windsor	1,840
Wyndmere	1,062
York	1,612

THE GEOLOGICAL FORMATIONS OF NORTH DAKOTA

Of the rock formations which compose the earth's crust but few are found in North Dakota and not all of these appear at the surface. Some are known to occur only from the records of deep wells and are concealed from view by the overlying strata. Before considering these formations somewhat in detail it will be well to review briefly the more important divisions of geological history.

The oldest rocks of the earth, those which are believed to have existed at one time in a state of fusion, belong to the Archean Era. These rocks are mostly crystalline, that is, they are composed of crystals of various minerals which have crystallized out of the original molten magma, and afford almost no evidence of the existence of life at this early period. The granites are examples of these ancient igneous or crystalline rocks, which form the foundation for the more recent beds.

The other great divisions of the earth's history, as recorded in the strata, are based on the life forms they contain. The earliest organisms were of simple structure and the same types existed all over the globe There has been a gradual development of animals and plants by which they have become more highly organized, more complex in structure and more like modern types. Now that this succession of life forms has been made out it furnishes the means of determining the age of the beds forming the earth's crust and the order in which they were laid down. Certain fossils are found only in strata of a certain age, others are restricted to beds of a different age. It is thus possible by means of the organic remains contained in them to determine the succession of the formations and to correlate strata in widely separated areas.

The Paleozoic Era, or the time of most ancient life, was characterized by forms for the most part very unlike those of today; the modern types of animals and plants were almost entirely wanting and the vertebrates were represented only by strange, armored fishes and amphibians. The Paleozoic was followed by

the Mesozoic Era or time of middle life, when great numbers of enormous reptiles inhabited the land, the sea, and the air and were the predominating forms. During the last or Cenozoic Era, signifying most recent life, modern animals and plants began to appear and the ancient types became almost extinct.

These three great divisions of geological history are in turn separated into shorter subdivisions or periods, each characterized by its own peculiar life forms. The Paleozoic Era, for example, is divided into the Cambrian, Ordovician, Silurian, Devonian and Carboniferous periods. The Devonian is marked by the culmination of the fishes, which were present in great numbers and of large size, and during the Carboniferous coal-forming plants grew in great abundance and luxurience.

Rocks belonging to all four grand divisions are present in North Dakota, although those of the Archean and Paleozoic are known only from well records. The formations which appear at the surface belong to the Mesozoic and Cenozoic eras and have a wide distribution throughout the state. The geological column of the formations found in North Dakota is shown in the following table.

TABLE OF NORTH DAKOTA GEOLOGICAL FORMATIONS

	FORMATIONS OCCURRING IN NORTH DAKOTA
CENOZOIC ERA:	
Pleistocene Period, represented by	Drift
Tertiary Period, represented by	Marls and limestones of Sentinel Butte.
MESOZOIC ERA:	
Cretaceous Period, represented by	Laramie Fox Hills Pierre Niobrara Benton Dakota
PALEOZOIC ERA:	
Devonian Period, Silurian Period, Cambrian Period, represented by	Shales, limestones and sandstones.
ARCHEAN ERA, represented by	Granites.

Archean.—The crystalline rocks of this era, which are chiefly granites, gneisses and schists, constitute the foundation upon which rest the later sedimentary formations. They have been reached in a number of deep wells in the eastern part of the state and across the line in Minnesota, and they undoubtedly form a part of the great Archean area of Canada and the Lake

Superior region. The granite outcrops in the vicinity of Big Stone lake, not many miles from the southeastern corner of the state. At Moorhead it is struck at a depth of 365 feet and at Grand Fork this ancient rock lies 385 feet below the surface, being covered by beds of clay, sand and gravel, with a thin layer of Silurian limestone immediately overlying it.

Cambrian.—The only evidence of the occurrence of strata of this age within the state is furnished by the record of the well at Grafton. Here the Archean is overlain by 288 feet of shales and sandstone which are believed to belong to the Cambrian.* Beds belonging to the same age are found farther north in Manitoba, south and west of Lake Winnipeg and they are undoubtedly continuous with those encountered in the Grafton well.

Silurian.—Silurian rocks underly a portion of the Red River valley and form quite a wide belt extending along the western shore of Lake Winnipeg and to the northwest. Fragments of Silurian limestone, containing characteristic fossils, are not uncommon in the drift of the northern countries and a boulder in which was a large Orthoceras was found as far south as Sargent county. They have been brought into the state by the continental glacier, probably from outcrops in Canada. In the Grafton well the beds referred to the Lower Silurian have a thickness of 317 feet, including the Galena and Trenton limestones, 137 feet; the Saint Peter sandstone, 93 feet, and the Lower Magnesian shales, 87 feet. In the deep well at Grand Forks, forty miles south, only one foot of Silurian limestone was encountered just above the granite. This may indicate either that the Silurian sea in which the strata were laid down did not extend far to the south or that, after having been deposited, the beds were eroded over this portion of their area, leaving only part of their original thickness. The Silurian formation appears to thicken quite rapidly toward the north, for while at Grafton, as already stated, it is 317 feet thick, sixty miles north at Rosenfield, Canada, it has increased to 892 feet. On the other hand, it thins out toward the west and at Morden, twenty-seven miles from Rosenfield and fifteen miles north of the international boundary, the Silurian is absent, as shown from the well record. The Dakota sandstone rests directly on the Devonian beds.

* Upham, Mono. U. S. Geol. Surv., No. xxv., p. 77.

Although rocks of the *Devonian* period are, so far as known, absent from North Dakota, they cover a narrow strip of territory lying just west of the Silurian area of Manitoba. At Morden, at a depth of 412 feet, a well penetrated 188 feet of red and gray shales and porous limestone believed to belong to the Devonian. It is not unlikely that these strata extend south some distance across the boundary.

CRETACEOUS

The strata of this period cover almost the entire state, except a narrow strip along the eastern border, and are of great economic importance; they contain thick seams of lignite and a variety of valuable clays, they supply an abundance of artesian water and have furnished the materials composing the rich soils of the region.

The Cretaceous rocks of North Dakota are a part of a larger area which forms a broad belt lying east of the crest of the Rocky Mountains and extending from Texas to the Province of Athabasca in Canada. These strata underlie the greater portion of the great plains region, though they are in small part covered by the later deposits of the Tertiary. The beds of this period are divided into the Upper and Lower Cretaceous, but only the Upper is found in this state.

The Cretaceous rocks of the Upper Missouri were studied as far back as 1854 by Meek and Hayden* who published what is known as the Upper Missouri Section. This has long been recognized as the standard of reference for the Cretaceous deposits of the interior regions and is given below.

UPPER MISSOURI SECTION OF MEEK AND HAYDEN

No. 5. Fox Hills group.
No. 4. Fort Pierre group.
No. 3. Niobrara group.
No. 2. Fort Benton group.
No. 1. Dakota group.

The Laramie formation, which is now included with the Cretaceous, was referred by these investigators to the Tertiary. They named the various subdivisions from the localities where the rocks were well developed. The Dakota sandstone received its name from Dakota City, Nebraska, where it was first studied; the Fort Benton clays from the fort of the same name on the Upper Missouri in Montana; the Niobrara clays and chalk rock from their extensive development along the Niobrara river near

* Proc. Acad. Nat. Sci. Phila., Vol. 8, 1856, pp. 265-286.

its junction with the Missouri; the Fort Pierre clays from Fort Pierre, South Dakota, in the vicinity of which they cover a large area; and the Fox Hills sandstone from the range of hills in South Dakota between the Cheyenne and Moreau rivers, west of the Missouri.

The Upper Missouri section of Meek and Haydən is modified by White in his correlation paper on the Cretaceous* and the following formations are recognized, with their equivalents in the earlier classification.

MEEK AND HAYDEN'S UPPER MISSOURI SECTION

Upper Cretaceous	Laramie formation	Not recognized as Cretaceous.
	Montana formation	Fox Hills group. Fort Pierre group.
	Belly River formation	Not recognized.
	Colorado formation	Niobrara group. Fort Benton group.
	Dakota formation	Dakota group.

The Belly river formation is found in Canada but does not occur in North Dakota.

In some large areas the chalky limestones and marls of the Niobrara are not present but are replaced by shales and sandstones. It is then very difficult, in the absence of characteristic fossils, to separate the dark shales of the Fort Benton from those of the Fort Pierre. To overcome this difficulty Clarence King proposed the term Colorado group for the clay members of the Cretaceous, making it include the Fort Benton, Niobrara and Fort Pierre groups of Meek and Hayden. But the Colorado formation, as the term is now commonly employed, is made to include only the Fort Benton and Niobrara, as given above, the Fort Pierre shales being placed in the overlying Montana formation.

The following table shows the Cretaceous formations which are found in North Dakota as they are now classified:

Laramie formation	
Montana formation	Fox Hills Pierre
Colorado formation	Niobrara Benton
Dakota formation.	

DAKOTA FORMATION

At the base of the Upper Cretaceous lies the Dakota sandstone, which is of great economic importance in North and South Dakota as the source of artesian water. This formation does not

* Bull. 82 U. S. Geol. Surv. 1891, p. 165.

outcrop anywhere in the state and lies at a considerable depth below the surface. In the eastern counties it has been struck at depths varying from 1,000 feet and less to 1,450 feet. The Devils Lake well reached the sandstone at 1,431 feet and at Jamestown it was encountered at about 1,450 feet, while further south it lies nearer the surface. The water enters the rock where it outcrops along the flanks of the Rocky Mountains and Black Hills, and since the formation dips toward the east it finds its way through the porous sandstone to a great distance from the surface exposures. The beds become saturated with water and serve as a reservoir for the artesian supply.

The Dakota sandstone, like most of the other formations of the Upper Cretaceous, has a very wide distribution, extending all the way from Texas thorough Kansas, Nebraska, and the Dakotas into Canada and west to the Rocky Mountains. It forms a very persistent and readily recognizable horizon.

In the absence of exposures within the state information concerning the character of this formation is derived partly from descriptions of the rock as found elsewhere and partly from the records of deep wells. The rock is a gray and brown sandstone containing layers of clay or shale. At the base of the formation there is sometimes a conglomerate. The sandstone varies from rock that is quite firm to sand which is barely consolidated and is frequently so soft as to be readily excavated with a pick. Fossil leaves are very abundant in places and the flora of the Dakota sandstone includes no less than 450 species of trees and other plants resembling those of today.

The thickness of the sandstone varies widely at different points but it is seldom more than 500 feet and is commonly less. At Morden, Manitoba, twenty-five miles northwest of Walhalla, the deep well record shows that the Dakota is ninety-two feet thick, formed of sandstone with interbedded shales and resting on Devonian strata. Elsewhere in the same district outcrops of the sandstone and wells penetrating it show that its thickness varies from fifty to 150 feet.

The beds of the Dakota formation are commonly regarded as of fresh water origin on account of the fresh water shells and abundant remains of land plants contained in them. In Texas and Kansas, however, marine forms are found and indicate marine conditions in those districts. The sandstone was probably formed in large bodies of fresh water, the materials com-

posing it being derived from the Rocky Mountain region on the west and in part also from a land mass in what is now the Black Hills area. The waste from the land was gathered and transported by the streams and deposited in these lakes, where it gradually accumlated to form the sandstone strata.

COLORADO FORMATION

The Colorado formation, as has already been stated, is composed of the Benton and Niobrara shales and limestone. It directly overlies the Dakota sandstone and in most cases at least is conformable with it.

Benton.—Outcrops of Benton shales within the state are few, although they are known to underlie large areas in the central and northern portions. Among the fossils collected during the past summer from the marl beds at the Portland Cement Mill, nine miles north of Milton, and sent to the Smithsonian Institution for identification, was a single imperfect imprint of Inoceramus. Dr. T. W. Stanton reports that this is probably referable to *Inoceramus labiatus* Schlotheim, which species is characteristic of the Benton formation. This may indicate that at least a portion of the beds at the cement mill belong to the Benton, although some of the fossils collected from these same calcareous strata have been referred to the overlying Niobrara, as shown on a succeeding page.

The deep well at Devils Lake passed through 1,403 feet of dark shale, the lower part of which may safely be referred to the Benton, and the Jamestown well penetrated about an equal thickness of shales belonging in part to the same formation. These beds appear to thin out toward the east and north, so that they are absent from the Red River valley. At Morden, Manitoba, not far west of the valley and about fifteen miles north of the international boundary, the combined thickness of the Benton, Niobrara and Pierre is only 289 feet, which shows a marked decrease in the thickness of these strata compared with that at Devils Lake. In the eastern part of the state the Pierre shales probably rest directly on the Dakota sandstone.

The Benton is composed of blue clay shales with occasional thin bands of limestone in some places. In Nebraska the upper portion of the formation is highly calcareous and chalky and comprises beds which were formerly regarded as belonging to

the overlying Niobrara.* On account of their fossils they are now placed in the Benton.

It is difficult, if not impossible, to determine the thickness of the Benton in North Dakota. This is largely owing to the fact that it cannot be distinguished in well records from the Niobrara and Pierre shales overlying it. It is probable, however, that in the central part of the state the Benton has a thickness of from 400 to 600 feet.

Niobrara.—The upper member of the Colorado formation is the Niobrara and it is often impossible to draw any sharp line of separation between this and the underlying Benton. The Niobrara, however, is usually characterized by the presence of a considerable thickness of calcareous and chalky strata.

The Niobrara beds outcrop in the northeastern corner of North Dakota along the Pembina, Little Pembina and headwaters of the Tongue rivers. These streams have eroded their valleys to a depth of 300 feet or more in the elevated region known as the Pembina Mountains, and along the sides of the valleys the Cretaceous rocks are in places excellently exposed.

At the point where the Little Pembina joins the Pembina river, on the north side of the latter stream near Mr. Mayo's brick plant, the following section is exposed. A large portion of the bluff has here recently broken away and slipped down to the bottom of the valley:

		FEET
3.	Soil and drift	6
2.	Light gray and buff, highly calcareous shale, containing layers of a slightly argillaceous chalk; these chalky beds contain abundant shells of Foraminifera, particularly *Globigerina cretacea* and *Textularia globulosa*	25
1.	Black and dark blue clay shales, passing above into a mottled gray calcareous clay or marl. The lower forty to fifty feet are covered by material which has slipped down from above and are not well exposed	290

All of the beds in the above section probably belong to the Niobrara, although some of the lower ones may be Benton.

Section at the Portland Cement Mill on the Tongue river, near the Cavalier-Pembina county line:

*Nebraska Geological Survey, Vol. 1, p. 138.

		FEET
8.	Unexposed to top of bluff, drift in part	50
7.	Bluish gray clay shale which on weathering breaks up into thin flakes; irregularly jointed, contains iron pyrites concretions and yellow spots and blotches of iron oxide. (Pierre shale)	70
6.	Unexposed	50
5.	Black and highly carbonaceous shale, containing abundant fragments of fossils; breaks readily into thin laminae and is cut by joints and irregular cracks which are filled with gypsum. Some of these gypsum seams are vertical while others are inclined at angles of about 45 degrees. Occasional thin layers of white clay occur toward the base	60
4.	Black, carbonaceous clay shale layers alternating with white clay seams; the black shale is similar to No. 5. The white bands, which are apparently formed by the leaching of the dark shale, are from one-half to five or six inches thick and have an acid taste	6 to 8
3.	Gray clay shale, resembling No. 2, but only slightly calcareous; much stained by iron oxide, which colors the joint faces brown	3 to 4
2.	Mottled, gray, highly calcareous clay or marl; is not shaly in structure but breaks irregularly into thick pieces; when weathered it often shows laminae one-quarter to one-eighth of an inch thick and crumbles readily into thin fragments. Contains much bituminous material and when fresh has a strong petroleum odor. Fossils common, but mostly fragments, though entire fishes are found in the beds. Contains several thin seams of lignite one to three inches thick	60
1.	Yellow clay, not very calcareous, exposed at river level.	

At the base of No. 2 of the above section there is a seven foot layer which is quite uniform in chemical composition and approaches closely that of a natural Portland cement rock. A large series of analyses show that the composition of this layer lies within the following range:

	PER CENT
Silica	9 to 15
Alumina	4 to 8
Iron oxide	2 to 3
Carbonate of lime	63 to 75
Carbonate of magnesia	1 to 2.5

The marl beds above this vary widely in composition, the percentage of lime carbonate ranging all the way from twenty to

seventy-five per cent. The layers very poor in lime are seldom more than one or two inches thick, while those highest in lime are usually not over two feet in thickness. These chemically different beds alternate one with another and there is no regular increase or decrease in the lime content toward the top or bottom of the section, the changes in composition being abrupt.

Highly calcareous, mottled, gray marls similar in appearance to No. 2 of the Cement Mill section were observed on the Little Pembina river near the sharp bend to the north and they have already been mentioned as occurring in the outcrop at the mouth of this stream, some thirty feet below the chalk beds.

It is interesting to note that these same calcareous shales, associated with chalk, are found farther north in Manitoba. The Niobrara formation, as described by the Canadian geologists,* comprises gray, chiefly calcareous shales, with a band of light gray chalk or mottled gray chalk marl about 200 feet thick. The beds are identified as belonging to the Niobrara by the constant presence of large numbers of Foraminifera.

The occurrence of chalk in North Dakota was unknown prior to its discovery the past summer on the Pembina river, although chalk had been found in the Niobrara of Texas, Kansas, Iowa, South Dakota and elsewhere.

For many years the text books on geology affirmed that there was no true chalk in the Cretaceous strata of America. But the Foraminifera characteristic of these white, calcareous deposits of the west and northwest have been recognized by many observers and the presence of true chalk in this country has been clearly set forth by Calvin† and others. Two species of Foraminifera which are very abundant in the chalk are *Globigerina cretacea* and *Textularia globulosa*, these and other microscopic shells making up a large part of the beds. Both of these species were readily identified in the specimens collected from the Pembina river outcrop, and leave no doubt that the material is chalk. The rock is not pure but contains some clay, as shown by the following analysis of an air dried sample of the chalk:

	PER CENT
Carbonate of lime	66.00
Carbonate of magnesium	1.40
Silica	16.06
Iron and aluminum oxides	8.65
Materials undetermined, and moisture	7.89
Total	100.00

*Trans. Roy. Soc. Canada, Vol. VIII., Sec. IV., 1890, p. 113.
†Iowa Geol. Surv., Vol. III., 1893, pp. 213-236.

The Portland cement marls lie below the horizon of the chalk and from these beds the following fossil vertebrates are reported by F. W. Sardeson*: the toothed bird *Hesperornis*, the teleost fish *Pachyrhizodus*, and *Platecarpus*, all referred by him to the Niobrara horizon. The vertebrae of a species of *Crocidilus*† have been found in the same strata.

From No. 2 of the Portland cement mill section small specimens of *Ostrea* and *Avicula* were collected, as well as fish scales and vertebrae, which are abundant. With these was found the imprint of an Inoceramus referred to *Inoceramus labiatus* Schlotheim,‡ which is characteristic of the Benton formation. The strata containing the above fossils probably lie near the contact of the Benton and Niobrara and it is therefore difficult to refer them with certainty to one or the other. The exact position of the horizon yielding the vertebrates, with reference to No. 2 of the Cement Mill section, is not known, though they are reported to have come from the Portland cement zone.

The humerus bone and vertebrae of a Plesiosaurus were some years ago found in digging a well in the vicinity of the cement mill. These recently came into the possession of the Geological Survey and were identified by Mr. C. W. Gilmore of the Smithsonian Institution.

Chalk is composed of the more or less broken shells of Foraminifera and other marine organisms, particularly the minute disc-like bodies known as Coccoliths. The entire shells of the Foraminifera are imbedded in the fine, calcareous mud which is formed from the debris of the skeletons of various simple forms. Chalk is formed in the clear, open sea and in comparatively deep water. The bottom of the sea on which it is deposited is so situated as to be, for the most part at least, out of reach of mechanical sediments brought from the land. This condition is commonly found in deep water and at some distance from shore, where the debris from land waste is largely absent. It was, then, in such a clear, open sea and under such conditions that the chalk beds of the Niobrara were formed. The presence of some clay in the chalk deposits of North Dakota indicates, however, that a little of the finer mechanical sediment from the land was mingled with the foraminiferal, calcareous debris at the time of its deposition.

* In personal letter to the writer.
† Identified by F. A. Lucas of the Smithsonian Institution.
‡ Fossils identified by Dr. T. W. Stanton of the U. S. Geological Survey.

The clays and marls composing the great bulk of the Niobrara are likewise of marine origin, as is indicated by their fossils. The beds were laid down in the sea, the materials which form them being derived chiefly from the waste of the land. The marls doubtless derived their lime carbonate from the abundant shells of marine organisms, many of which have been ground up and intimately mixed with the mechanical sediments, forming the calcareous clays.

The Niobrara formation, considered as a whole, is composed of gray to black clay shales, marls and some beds of light gray and buff argillaceous chalk.

The total thickness of the Niobrara in the northeastern part of the state could not be determined since the lower limits have not yet been defined. If all the beds appearing in the section at the mouth of the Little Pembina belong to the Niobrara, its thickness at that point is at least 300 feet. It is less than 200 feet at the Portland Cement Mill even if the black, carbonaceous shales (Nos. 4 and 5), overlaying the marl, are included in the Niobrara. In Manitoba the thickness of this formation varies from 128 to 545 feet.

MONTANA FORMATION

Pierre.—The Pierre shales play an important part in the geology of North Dakota, both on account of their wide distribution throughout the central and eastern portions and also because they have furnished the great bulk of the material of the drift and soils over the same region. They cover nearly, if not quite as large an area as the Laramie strata which occupy the western half of the state. The shales overlie the beds of the Niobrara ard are entirely conformable with them.

The strata of the Pierre make up a large part of the conspicuous, wooded escarpment bordering the Red River valley on the west and known as the Pembina Mountains. They appear at many points along the edge of these highlands, particularly where they have been cut into by such streams as the Pembina, Little Pembina, Tongue and Park rivers. They are well shown in the vicinity of Milton, and further south they outcrop about one and a half miles north of Niagara, along the North Branch of the Turtle river. The shales are exposed at many points along the Sheyenne river from its headwaters among the drift hills west of Devils Lake to the bend near Lisbon. At Valley

City the Pierre shales rise at least 120 feet above the river and appear along both the James river and Pipestem creek, several miles above Jamestown.

Throughout the larger part of their extent, however, the beds are buried under a greater or less thickness of glacial drift. The rock debris forming the superficial deposit is composed chiefly of fragments of the shale, mingled with some foreign material, and this indicates that the Pierre shales form the bed rock beneath the drift.

The general character of the beds is shown in the sections which follow. The first is one and a quarter miles east of Valley City, in a cut along the Soo railroad:

	FEET
4. Drift and soil	1 to 3
3. Black clay shale, with yellow iron stains in spots and blotches. Upon exposure to the weather it crumbles into thin flakes	6 to 8
2. Light gray and cream-colored clay shale, containing some layers of a rather calcareous clay	20
1. Unexposed to river	60

The light colored clays of No. 2 are readily distinguished from the dark ones above even at a distance, and the contact between them can be traced for miles along the bluffs. There is a marked difference in the way the two clays weather.

The same beds are exposed along the Sheyenne river at the sharp turn one mile south of Valley City, where the stream cuts against the bluff. One hundred feet of light gray clay shale, representing No. 2 of the above section, are exposed here, overlain by ten to twenty feet of black shale. The light colored shale breaks into thick, irregular pieces and not into thin fragments or flakes, as the black clay. The upper portion, for several feet below the dark shale, is cream-colored and more calcareous than the lower beds.

An analysis of these more calcareous, cream-colored layers gave the following result, the specimens being air dried:

	PER CENT
Carbonate of lime	75.00
Carbonate of magnesium	3.00
Silica	30.70
Iron and aluminum oxides	15.20
Materials undetermined and moisture	6.10
Total	100.00

The Pierre shales are well exposed on Pipestem creek at the abrupt bend one mile south of Parkhurst, the first station north of Jamestown on the Northern Pacific. Seventy-five feet of dark clay shales are here seen. They are cut by several sets of joints and show many yellow spots and blotches caused by iron oxide. The shales are readily broken into thin slabs with conchoidal surfaces, and under the action of the weather they crumble into thin fragments. Some nodules of iron pyrites are scattered through the beds. Similar shales outcrop on the James river five miles north of Jamestown, and at other points along the valley.

As shown in numerous outcrops the Pierre formation is composed of black, bluish, greenish and light gray shales. Some of the beds are rather calcareous and occasionally they are sandy. The shales disintegrate readily into small, flaky fragments which cover the surface to a depth of from a few inches to several feet. They commonly show yellow iron stains and are cut by joints. The shales of the Pierre are quite uniform in character throughout the state and can be readily recognized.

Fossils are found only sparingly in these strata. The more common forms which occur are *Baculites ovatus* Say, *Inoceramus sagensis* Owen, and *Scaphites nodosus* Owen. It usually requires careful and prolonged search to discover any fossils and many of the beds are barren of them.

The Pierre shales show a wide variation in thickness in different localities. They probably attain their greatest thickness in the northeastern part of the state, in the Pembina Mountain region. As previously stated, this elevated area is formed in great part of these shales, which are here at least 300 to 400 feet thick and they probably exceed this toward the west and north. Toward the east, however, they gradually thin out and are absent from the Red River valley.

The Pierre formation is a marine deposit and the materials composing it were laid down as fine mud or clay in the sea. Shales are formed of the finer debris from the land and the absence of much sand and coarse sediment indicates that the beds accumulated at some distance from the shore, where the coarser materials did not reach.

The latter are deposited near the coast and the finer and lighter detriturs is transported by the currents to a greater distance from land before settling to the bottom.

Fox Hills.—This upper member of the Montana formation receives its name, as already stated, from its prominence in the Fox Ridge or Fox Hills, lying between the Cheyenne and Moreau rivers of South Dakota. So far as our present knowledge goes it is probable that the Fox Hills sandstone appears at the surface at only a few points in North Dakota.

During the summer of 1903 members of the survey collected a brown, friable sandstone on the Cannon Ball river about eight miles above its mouth. This rock contained the fossil shells *Tancredia americana* M. & H. and *Callista* sp., possibly *Callista nebrascensis* M. & H. There are marine Cretaceous forms and the sandstone beds containing them doubtless belong to the Fox Hills formation.* Certain sandstones occurring in Emmons, Burleigh and adjoining counties have been referred by Todd† to the Fox Hills, such a correlation of the beds being based upon Hayden's statement that the Fox Hills sandstone was evident about Long Lake. But there appears to be nothing to indicate that these are not Laramie in age. Sandstone strata are not uncommon in the overlying Laramie formation, where they are formed by the local hardening of beds of sand. Such indurated sandrock, belonging undoubtedly to the Laramie, is found near Velva, Sims, capping the buttes near Dickinson, and elsewhere. In the absence of fossils it is difficult, if not impossible, to determine definitely the age of the sandstones at Long Lake, Steele and Long Lake creek, in Emmons, Burleigh and Kidder counties, but from their position and stratigraphic relations they are more likely to belong to the Laramie.

In the Turtle Mountain region outcrops of sandstone or other Cretaceous rocks are extremely rare on account of the thick drift deposits, but there is every reason to believe that the strata which do outcrop there all belong to the Laramie. The presence of Laramie coal and clays well toward the base of the Turtle Mountains indicates that the Fox Hills sandstone, if present, must lie at some depth below the surface.

A considerable area in the western part of the state is probably underlain by this sandstone but it is covered by the younger Laramie beds and the still more recent drift sheet. Across the line in South Dakota this formation has quite a wide distribution west of the Missouri, with smaller areas east of that stream.

*Fossils identified by Dr. T. W. Stanton of the U. S. Geological Survey.
†Bull. No. 144, U. S. Geological Survey, p. 55.

The Fox Hills formation "consists largely of gray and yellow, thin-bedded sandstone, which sometimes weathers to a pink color. With these are associated incoherent sands and arenaceous clays, the whole occupying 100 to 150 feet in thickness. The sandstones are rarely more than six inches in thickness, and are frequently much thinner. They attain prominence in the topography of the country, especially in the vicinity of streams, by their durability. They are found capping cliffs and bluffs in a very clear cut and picturesque manner. They are cut by frequent joints which traverse the layers in lines usually at right angles to one another. The sandstones are frequently pierced with stems of plants standing vertically."* In South Dakota the Fox Hills beds furnish a building stone of fair quality.

LARAMIE FORMATION

No other geological formation in North Dakota is of so great economic importance as the Laramie, and no other, with the possible exception of the Pierre, covers so large an area within the state. It contains rich and practically inexhaustible deposits of coal, as well as a variety of high grade clays suitable for fire brick, pottery and ornamental and common brick. It is the sculpturing of the clays and sands of the Laramie which has given rise to the unique and picturesque scenery of the bad lands. Then, too, no other formation in the state forms the surface rock over such an extensive area, thus furnishing many excellent exposures. Not only have the Missouri and its tributaries cut deep valleys in these strata and exposed vertical sections hundreds of feet in height, but over a large portion of its extent the Laramie rocks lie immediately beneath the soil, with no covering of drift to bury them from sight.

It has been said that this formation represents one of the most interesting epochs in North American geological history. There has been much discussion regarding the age of the deposits, some geologists referring them to the Cretaceous, others to the succeeding Tertiary period. This uncertainty as to the age of the Laramie strata is due to the fact that the plant remains resemble those of the Tertiary, while the vertebrate life is distinctly Cretaceous. The formation is now regarded as holding a transitional position between those two periods, and is related to the Mesozoic on the one hand and to the Cenozoic on the other.

*Todd, South Dakota Geological Survey, Bull. No. 1, p. 95.

The Laramie beds occupy the entire western half of the state with the probable exception of the greater portions of Bottineau and McHenry counties. So far as known at present the formation is not found beneath the drift in those two counties, although later explorations may disclose its presence. As will be seen from the map (Plate I), the Laramie extends as far east as the eastern edge of Emmons, Burleigh, McLean and Ward counties, and perhaps farther. Outcrops of the clays, sands and lignite seams are common along all the larger streams of the region—the Missouri, Little Missouri, Cannon Ball, Heart and Knife rivers with their tributaries. Perhaps the best exposures are found in the bad lands of the Little Missouri, where the conditions are particularly favorable for the study of the Laramie.

The character of the formation is best shown by the following detailed sections, taken at a number of widely separated points;

SECTION IN THE BLUFFS OF THE MISSOURI, FOUR MILES SOUTHEAST OF WILLISTON

		FEET	INCHES
13.	Drift, containing many boulders	1 to 10	
12.	Clay, light gray	4 to 6	
11.	Lignite seam, not well exposed	1 to 2	
10.	Clay, sandy, light gray, with yellow bands due to presence of limonite similar to Nos. 5 and 8	30	
9.	Lignite seam	..	8
8.	Sandy clay shales similar to No. 5 and containing many ferruginous sand concretions	20	
7.	Light bluish gray clay, not sandy, crumbles readily into thin laminae; much softer and more easily weathered than No. 6	2	
6.	Clay shale with peculiar vertical fracture; is broken up into long, slender and irregular columnar pieces by numerous vertical cracks. This clay shale is harder than the clays above and below and hence resists weathering better	..	10
5.	Light gray, sandy, clay shale with yellow, limonitic bands	30	
4.	Lignite seam	8	
3.	Light gray, sandy clay, similar to No. 1, but has fewer concretions. Contains leaf impressions and silicified		

		Feet	Inches
	wood. One silicified trunk twelve inches in diameter lies immediately above the coal seam (No. 2)......	50	
2.	Lignite seam	3	
1.	Light gray, sandy clay, containing abundant ferruginous sand concretions scattered through the clay; selenite crystals also numerous	30	

The base of the section is from forty to fifty feet above the river.

SECTION ON THE SOUTH SIDE OF THE MISSOURI, THREE MILES BELOW WILLISTON

		Feet	Inches
22.	Drift containing large numbers of boulders.............................	5 to 10	
21.	Gray sandy clay with ferruginous sand concretions	6	
20.	Lignite seam		3
19.	Clay shale, gray, with thin lignite parting near base	4	
18.	Gray, sandy clay with some sand concretions and several thin, yellow, limonitic bands near the top.........	30	
17.	Brown, sandy clay with plant impressions................................	1	
16.	Gray, sandy clay......................	4	
15.	Lignite	2	
14.	Sandy, gray clay......................	8	
13.	Lignite seam	..	6
12.	Gray and very sandy clay, containing abundant concretions of sandstone and lenses and bands of the same material. These concretionary masses are harder than the rest of the rock and on weathering they stand out on the face of the slope or form the cap of the earth pillars. The concretions vary in size from several inches to eight and ten feet or more	45	
11.	Clay with abundant silicious limonite nodules	4	
10.	Clay shale, brown, fissil	1	6
9.	Clay containing many limonitic nodules.................................	10	
8.	Lignite seam		1
7.	Clay, sandy, gray or yellow, contains silicified stumps of trees.............	10	
6.	Lignite	1	

		Feet	Inches
5.	Clay, light gray, not sandy	3	
4.	Lignite seam		1
3.	Light gray, sandy clay	30	
2.	Gray sandstone, fine-grained	1	6
1.	Clay, light gray (exposed)	10	

SECTION ON WHITE EARTH RIVER, ONE AND A HALF MILES NORTH OF TOWN OF WHITE EARTH

22.	Drift	2 to 6	
21.	Gray, sandy clay, with large sandstone concretions	30	
20.	Lignite seam		8
19.	Gray clay	8	
18.	Sandstone, weathering into concentric, concretionary masses, soft, gray	1	6
17.	Gray, sandy clay, with yellow, ferruginous lines and bands, not well exposed	30	
16.	Lignite seam		2
15.	Clay, gray, sandy, with sandstone concretions	25	
14.	Soft, gray, shaly sandstone	2	
13.	Gray, sandy, clay, with yellow ferruginous bands	7	
12.	Lignite and brown, fissil shale		6
11.	Gray and very sandy clay	25	
10.	Lignite seam, not well exposed	2	
9.	Gray clay containing much selenite	20	
8.	Gray sandstone	1	6
7.	Gray clay	8	
6.	Yellow clay		2
5.	Gray clay	3	
4.	Yellow, ferruginous band		½
3.	Gray clay	1	6
2.	Clay, brown, fissil, with some lignite		2
1.	Gray clay containing crystals of selenite	20	

SECTION AT THE BIG BEND OF THE MISSOURI RIVER TWO MILES NORTHWEST OF COAL HARBOR

38.	Drift	30	
37.	Clay shale, chocolate brown below, gray above	5	
36.	Lignite seam	3	6
35.	Clay shale, containing plant impressions	1	6
34.	Fine, argillaceous sand	8	
33.	Gray, laminated clay shale	5	
32.	Lignite seam		3 to 5
31.	Gray clay shale	5	

		Feet	Inches
30.	Sandy, gray clay stained yellow in spots by iron oxide	6	
29.	Brown clay shale with thin lignitic partings		6 to 10
28.	Light gray clay, growing sandy above	5	
27.	Gray, sandy clay with ferruginous nodules and yellow, limonitic bands	20	
26.	Clay shale, gray and yellow in alternating layers, with thin, yellow, limonitic bands. Contains many *Unios* and gastropods including *Viviparus trochiformis*	4	
25.	Brown and black, brittle, coaly shale	1	
24.	Brown clay shale	1	
23.	Lignite seam		6 to 8
22.	Brown, clay shale with plant remains		10
21.	Lignite seam		2 to 3
20.	Clay with abundant plant impressions		2
19.	Fine, argillaceous sand	3	
18.	Gray clay shale, crumbles readily into thin flakes	1	
17.	Thin lignite seam		½
16.	Gray and yellow clay shale in alternating layers; crumbles readily on exposure to the weather. Contains *Unios* and gastropods	4	6
15.	Clay shale, chocolate brown, with fossils similar to those in No. 16	4	
14.	Lignite seam		10
13.	Clay shale, gray, weathers into thin flakes	1	6
12.	Gray and yellow, sandy clay with ferruginous nodules	10	
11.	Lignite seam with some coaly shale		8
10.	Gray clay shale	4	
9.	Lignite seam and brown, carbonaceous clay		2
8.	Gray, sandy clay, stained yellow in spots by iron oxide. Contains very many sandy, ferruginous nodules, distributed mostly in bands. The nodules stand out on the surface and fragments of them cover the slope. Also contains large sandstone concretions and lenses	31	
7.	Gray and yellow argillaceous sand	4	
6.	Gray clay, with no sand, and containing nodules of iron oxide	1	

		Feet	Inches
5.	Lignite seam	3	
4.	Gray clay shale	1	
3.	Lignite seam, entire thickness not exposed, but at least	4	
2.	Sandy clay shale	10	
1.	Unexposed to river	15	

SECTION ON SQUARE BUTTE CREEK, IN SOUTHEASTERN OLIVER COUNTY, ONE MILE ABOVE MR. KIEBERT'S RANCH

		Feet	Inches
11.	Soil	1	6
10.	Drift, with numerous boulders and pebbles of igneous rock; the till is composed largely of the underlying clay and sandstone	2 to 6	
9.	Soft, yellow sandstone; many of the beds are more or less concretionary and uneven in thickness. The rock contains much iron oxide which stains it brown in places	25	
8.	Dark, chocolate brown clay shale		6
7.	Sandstone, soft, yellow, concretionary	2 to 3	
6.	Brown and yellow, sandy clay shale, alternating with yellow and gray sandstone beds, the layers varying from three to six inches in thickness	6	
5.	Soft, yellow sandstone	$1\frac{1}{2}$ to 2	
4.	Hard, sandy, clay shale. This bed thins out and disappears at south end of the exposure		8
3.	Yellow sandstone, laminated above and breaking into thin slabs, more massive below	2	
2.	Gray and brown clay shales alternating with yellow and gray sandstone layers, the beds varying in thickness from one to six inches. The chocolate brown shale contains fragments of carbonized wood	20	
1.	Sandy, gray, yellow and brown clay shale, jointed, with a few sandstone strata two to three inches thick	40	

SECTION ON THE HEART RIVER, ONE MILE SOUTH OF DICKINSON, AT THE CLAY PIT OF THE DICKINSON PRESSED BRICK & FIRE CLAY COMPANY

12. White, sandy, coarse-grained and very pure fire clay. This is composed chiefly of quartz sand, with some white kaolin clay which coats the

		FEET	INCHES
	sand grains, fills the interstices and gives the beds their white color......	7	
11.	Light gray to white, very fine-grained and pure pottery clay...............	1 to 2	
10.	Blue, fine-grained clay................	5 to 6	
9.	Gray sand, fine-grained, shows cross-lamination..........................	35	
8.	Clay, very sandy....................	4	
7.	Lignite and brown carbonaceous shale.	1	
6.	Sandy clay..........................	4 to 5	
5.	Lignite seam........................	2 to 4	
4.	Gray, sandy clay.....................	6	
3.	Gray, fine-grained, argillaceous sand ..	10	
2.	Unexposed...........................	6	
1.	Lignite seam, exposed in bed of river..	8	

SECTION IN THE BLUFFS OF THE LITTLE MISSOURI AT MEDORA

The beds are well exposed in the ravine which has cut back into the bluff just below the town.

		FEET	INCHES
40.	Shaly sandstone, gray weathering to yellow, finer grained than No. 39. Contains cherty layer................	15	
39.	Sandstone, dark-gray, rather soft, coarse-grained, massive; forms vertical escarpment near top of bluff......	45	
38.	Lignite seam and coaly shale..........		1 to 4
37.	Clay shale, gray and yellow...........	9	
36.	Lignite seam..........................		3 to 4
35.	Clay shale...........................		6
34.	Gray, fine-grained, shaly sandstone....	6	
33.	Yellow clay shale.....................	1	6
32.	Lignite seam..........................		6
31.	Gray clay shale.......................	1	
30.	Gray, sandy shale.....................	6	
29.	Clay shale, gray......................	1	6
28.	Chocolate brown clay shale with thin lignite seam.........................	1	
27.	Gray clay shale.......................	4	
26.	Soft, shaly sandstone, gray and buff, laminated, fine-grained; in places forms hard sandstone ledge projecting beyond the softer shales above and below.............................	15	
25.	Gray and yellow clay shales. with some sandy layers........................	5	
24.	Chocolate brown clay shale with plant impressions..........................		4
23.	Lignite seam..........................	1	6

		FEET	INCHES
22.	Clay shale, gray and yellow, with some sandy layers and a thin streak of lignite	30	
21.	Sandy shale passing above into a compact, hard, fine-grained gray sandstone. This rock forms a projecting ledge	3 to 4	
20.	Gray and yellow clay shale	5	6
19.	Fine-grained sandstone, forming projecting ledge	2	
18.	Gray and yellow clay shale	4	6
17.	Gray, fine-grained, sandy shale	6	
16.	Lignite streak and chocolate brown shales		½
15.	Gray, sandy shale and soft sandstones. In places the sandstone is cemented into hard rock, forming projecting ledge	7	
14.	Gray clay shale	1	
13.	Chocolate brown shale		8
12.	Lignite seam	1	
11.	Gray and yellow clay shale	25	
10.	Chocolate brown shale	2	
9.	Lignite seam	4	
8.	Chocolate colored c'ay shale with abundant plant remains, mostly stem impressions	1	
7.	Gray clay shale	3	
6.	Sandy shale and fine-grained sandstone	16	
5.	Clay shale	4	
4.	Sandy clay shale	6	
3.	Gray clay shale	1	
2.	Lignite seam	9	
1.	Gray clay shales, not well exposed, to river	40	

PICKET BUTTE SECTION, CUSTER TRAIL RANCH, ON THE LITTLE MISSOURI FIVE MILES SOUTH OF MEDORA

67.	Gray clay shale, growing sandy above to top of butte	12	
66.	Lignite seam		4 to 6
65.	Gray, sandy clay shale	6	
64.	Laminated, gray sandstone, rather hard, forms projecting ledge	4	6
63.	Gray clay shale	2	
62.	Brown shale containing plant impressions and shells	1	6

		FEET	INCHES
61.	Gray clay shale crumbling readily into thin flakes	6	
60.	Lignite seam		7
59.	Gray clay shale, passing above into chocolate brown shale	1	
58.	Fine-grained, soft, gray sandstone	16	
57.	Gray clay shale	2	
56.	Gray and yellow sandstone	12	
55.	Gray clay shale	4	6
54.	Chocolate brown shale		4
53.	Lignite seam	1	
52.	Chocolate brown clay shale		6
51.	Clay shale, gray	7	
50.	Brown clay shale with plant impressions		1
49.	Gray clay shale	2	6
48.	Sandstone, soft, gray and yellow, fine-grained, with thin bands of yellow, limonitic clay	20	
47.	Gray clay shale, growing sandy toward top and graduating into the overlying sandstone	2	
46.	Lignite seam, the lignite being of excellent quality	4	
45.	Chocolate brown clay shale, with plant impressions		9
44.	Gray clay shale. The lower portion of this member and No. 43 below contain great numbers of selenite crystals. Some of these are eight to ten inches long and they are scattered thickly through the clay	4	6
43.	Chocolate brown clay shale with abundant plant impressions		6
42.	Lignite seam, the coal of good quality	6	
41.	Brown clay shale, similar to No. 43		8
40.	Gray clay shale	5	
39.	Black, coaly shale, with some lignite		3
38.	Soft, gray sandstone, fine-grained and showing cross-lamination; contains pyrite nodules which have altered extensively into limonite. It has layers of brown, ferruginous, hard sandstone, forming projecting ledges	34	
37.	Lignite seam	5	
36.	Chocolate brown clay shale with carbonized wood		6

		FEET	INCHES
35.	Soft, gray sandstone, fine-grained, with several bands of clay two or three inches thick	5	
34.	Gray, sandy clay shale	1	6
33.	Thin lignite seam		½
32.	Gray clay shale		11
31.	Sandstone, soft, fine-grained, gray	1	2
30.	Gray and yellow clay shale	1	
29.	Soft, gray sandstone, fine-grained	1	6
28.	Clay shale, gray and yellow	6	
27.	Brown clay shales with thin lignite parting		3
26.	Lignite seam		5
25.	Chocolate brown shale with plant remains	1	
24.	Gray clay shales	5	
23.	Gray, soft, fine-grained sandstone	4	
22.	Sandy clay shales, yellow and gray	3	
21.	Sandstone, soft, gray	4	
20.	Gray and yellow clay shales, non-arenaceous, and sharply marked off from sandy beds above and below	2	6
19.	Soft, gray, fine-grained sandstone	6	
18.	Yellow and gray clay shales		10
17.	Lignite seam, with some selenite crystals		2 to 3
16.	Chocolate brown clay shales		4
15.	Clay shales similar to No. 13, with yellow band at bottom	5	
14.	Gray, fine-grained sandstone	6	
13.	Gray clay shale, soft and crumbles readily into thin fragments; yellow band at top	2	
12.	Brown clay shale	1	
11.	Black, coaly shale with some lignite		9
10.	Chocolate brown, sandy shale, with carbonized wood	3	
9.	Gray, soft, shaly sandstone, fine-grained and laminated; contains pyrite nodules partially altered on surface to limonite	4	
8.	Alternating layers of gray and yellow clay shale containing fragments of shells	4	6
7.	Shaly sandstone, yellow, fine-grained	1	
6.	Gray clay shale		5
5.	Chocolate brown, coaly shale with some lignite		6
4.	Yellow clay shale		10

		FEET	INCHES
3.	Chocolate brown shale with carbonized wood		1 to 2
2.	Gray clay shale	5	
1.	Unexposed to river	15	

It will be noticed that in the above section there are no less than twelve seams of lignite, varying in thickness all the way from one-half inch to six feet, and all occurring within a vertical range of less than 260 feet.

SENTINEL BUTTE SECTION

29.	Alternating layers of highly calcareous gray clay and very fine-grained, compact, brittle, gray limestone, finely laminated and more or less silicious. Some of the sandstone beds weather into thin laminae, one-sixteenth of an inch thick and less	7	
28.	Very calcareous, gray clay, weathering to a greenish color	18	
27.	Gray, hard sandstone	40 to 50	
26.	Gray and yellow, sandy clay	25	
25.	Brown clay and thin seam of lignite	1	6
24.	Gray and yellow, sandy clays	48	
23.	Lignite seam		6
22.	Soft, fine-grained, argillaceous sandstone	12	
21.	Brown and gray clay shale containing many selenite crystals	4	
20.	Soft, fine-grained sandstone	1	
19.	Lignite seam	1	to 18
18.	Chocolate brown clay shale, with carbonized wood	1	
17.	Bluish gray clay	10	
16.	Gray sand, cemented in places into soft sandstone	12	
15.	Not well exposed, but probably clay shale	50	
14.	Lignite seam		2 to
13.	Gray sandy clay	32	
12.	Gray clay shale with no sand	2	
11.	Lignite seam	6	
10.	Sandy clay shale, colored brown above	5	
9.	Fine, gray sand	4	
8.	Gray, sandy clay shale, containing nodules, similar to No. 6	14	
7.	Finely laminated sand	4	

		FEET	INCHES
6.	Gray, sandy clay shale with ferruginous bands	8	
5.	Chocolate brown, sandy clay shales....	1	
4.	Gray clay shales with no sand	5	
3.	Sandy, gray clay, containing abundant silicious iron nodules, arranged mostly in bands at certain horizons; these hard nodules project from the surface of the softer clay, and also cap small clay columns........................	20	
2.	Unexposed, includes some sand	20	
1.	Lignite seam, outcropping in bottom of ravine near the east end of the butte, exposed	20	

Nos. 28 and 29 of the above section are probably Tertiary.

The foregoing sections may be taken as representative of the Laramie formation. They show that it is composed of alternating beds of clay and sand, together with seams of lignite. In places the sand layers are cemented into a firm, hard sandstone, but commonly they form incoherent beds, readily crumbling in the hand. These arenaceous strata, however, resist the action of weathering agencies better than the clays and their outcropping edges form vertical ledges, often projecting beyond the clays. The presence of the sandy beds can thus commonly be detected at a distance by the character of the slope.

Probably two-thirds of the thickness of the Laramie is made up of clays, though this varies in different places. These clay shales range in composition from very pure clays through those containing an increasing percentage of sand to beds with only a small proportion of clay. The argillaceous strata thus graduate into the sandy layers through every intermediate mixture of clay and sand, and we have sandy clays and clayey sandstones. Many of the so-called clays are, strictly speaking, impure sandstones. In some cases the change from clay shale to sand is abrupt, in others it is gradual, the clay becoming more sandy near the line of contact.

One of the most marked features of the Laramie is this rapid alternation of sand and clay strata, and the frequent occurrence of beds of lignite. The colors of the clay are white, gray, yellow, brown and red, the grays and yellows predominating. The brown layers are rich in plant remains, and it is to the presence of this carbonaceous matter that they owe their color. These

Fig. 1. Large sandstone concretions in the Laramie beds. The concentric layers are well shown. On Square Butte creek

Fig. 2. A nearer view of one of the large sandstone concretions

varied colors give the formation its marked banded appearance and add greatly to the beauty and variety of the landscape.

Crystallized gypsum or selenite is common in the clay and in some layers this mineral is very abundant. It is particularly liable to occur in the brown layers immediately beneath the lignite seams, as shown in the Picket Butte section, where a clay bed (No. 44) is packed full of crystals of gypsum. The crystals are often very much elongated, some being found eight and ten inches in length, and are seldom perfect, the faces being more or less etched.

Of still more frequent occurrence are the ferruginous nodules and concretions, composed either of iron pyrites or of limonite. They usually contain more or less silicious or argillaceous material and after exposure to the weather stain the clay about them yellow. Many of the clay slopes are thickly dotted with these nodules and concretions of all shapes and sizes up to several feet in diameter. Thin, impure, limonite or clay ironstone bands, yellow in color, are not uncommon in the clays.

Another feature of the Laramie formation is the presence of silicified wood, often preserving very perfectly the original structure of the trees. Large stumps several feet in diameter and fragments of the trunks and branches are common.

Beds of sand, sometimes hardened into a firm sandstone compose a large part of the Laramie formation. The sand varies from coarse to fine and in color is usually some shade of gray, though yellows and browns are found. Mingled with the sand is a varying proportion of clay, so that it passes into an argillaceous sand and sandy clay.

A marked characteristic of the sandy strata is the presence in them of sandstone concretions and lenses. These are made up of concentric layers, are much harder and more compact than the inclosing mass and are frequently of great size, some being observed twenty to twenty-five feet in diameter. Many resemble large lenses of sandstone but their concentric structure shows their true character. On the Custer Trail Ranch, near Medora, curious log-like concretions were observed. Three of these lay parallel to each other a few feet apart, with a length of twenty to thirty feet and a diameter of two to four feet. They resemble saw logs in appearance and size and are divided into sections by transverse joints. These are shown in Plate XXIX.

Similar log-like concretions in the Laramie beds of northwestern South Dakota have been described by Todd.* Occasionally the sand strata are cemented into a hard, firm sandstone, like that occurring near Velva and Sims, capping the buttes in the vicinity of Dickinson, Gladstone and elsewhere. The top of the Laramie formation is often composed of beds of sandstone. These are well shown on the summit of Sentinel Butte, where they are forty to fifty feet thick and form vertical cliffs, with great blocks of the same material at their base. This upper sandstone is also well developed farther south in the Cave Hills, near the boundary between North and South Dakota. In most of these sandstones the cement which holds the sand grains together is silica; but in the rock found near Velva it is carbonate of lime. The sandstone is either in thin layers two to six inches in thickness or in thick, massive ledges.

The most striking characteristic of the Laramie is the large number of lignite seams contained it it. Some sections along the Little Missouri show no less than twelve within a thickness of 250 feet, ranging all the way from an inch to six feet and over. If we add to this number the five seams which outcrop in Sentinel Butte it makes at least seventeen lignite veins between the river level at Medora and the top of that butte, a vertical distance of about 860 feet.

The frequency of the seams and their aggregate thickness are well shown in the records of the deep wells at Medora and Dickinson.† The Medora well passed through 941 feet of Laramie strata without reaching their base and encountered no less than seventeen lignite seams with a total thickness of more than sixty feet. The Dickinson well had a depth of about 1075 feet and penetrated sixteen seams, their aggregate thickness being about fifty-five feet. The lignite does not appear to be confined to any particular horizon or horizons, but the seams are distributed quite uniformly throughout the formation. They vary in thickness all the way from an inch to forty feet. Seams from six to ten feet thick are common and thinner ones are of still more frequent occurrence. Where a bed of lignite is followed for any considerable distance it is found to thin out and finally disappear. It may be replaced further on by another seam either at the same level or at a higher or lower elevation. This want of persis-

*South Dakota Geol. Surv., Bull. No. 2. p. 59.

†Darton, Seventeenth Ann. Rep. U. S. Geological Survey, pt. 2, p. 663.

Fig. 1. Large log-like concretions in the Laramie formation. Custer Trail ranch near Medora

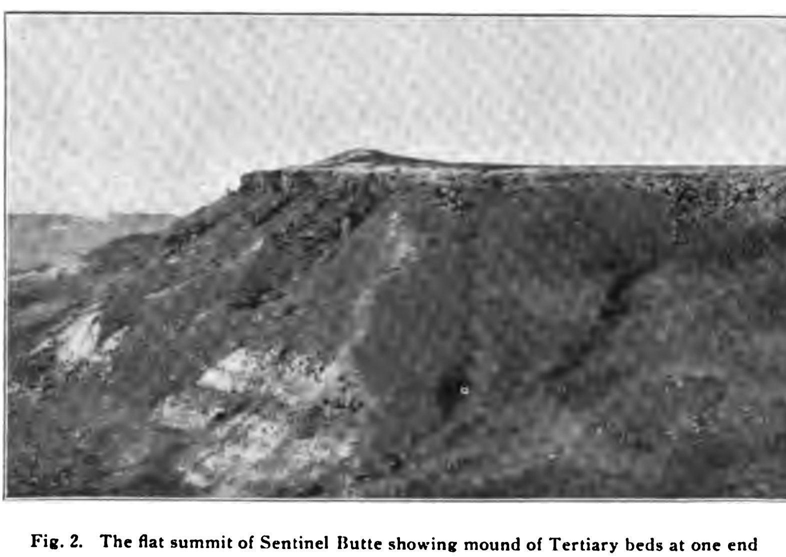

Fig. 2. The flat summit of Sentinel Butte showing mound of Tertiary beds at one end

tence not only in the lignite beds but in the other strata of the Laramie, is a notable feature of these deposits. Many layers thin out in less than a mile, while others may be traced several miles before they disappear and are replaced by others. The lignite seams thus have the shape of flattened lenses, thicker at the center and growing thinner toward the edges. To a greater or less extent they overlap each other. Since they do not persist over very large areas it is not safe to correlate seams in exposures separated by more than a few miles.

Another feature of the Laramie clays and sands which cannot fail to attract the notice of even the casual observer is the immense quantity of burnt and fused clay seen on every hand, wherever there are extensive outcrops of the beds. This red scoria, as it is commonly called, is merely clay which has been subjected to the great heat produced by the burning lignite seams. The latter take fire by spontaneous combustion, or probably in some instances from prairie fires, and burn often for many years. This burning of the lignite has doubtless been going on ever since the formation of the seams and has resulted in the production of a suprisingly large amount of red scoria. Bands of this material may be traced for miles along the bluffs of the Little Missouri and represent the horizons of burned out lignite seams, the adjoining clays having been burned and more or less fused as though in a brick kiln

The Laramie beds have a thickness of at least 1,800 feet in the western part of the state. The Medora well with its depth of 941 feet did not pass through them and Sentinel Butte rises 860 feet above the curb of the well. This is perhaps the maximum thickness of the formation in North Dakota and it grows thinner toward the east until it is only a few hundred feet and less beyond the Missouri river.

Fossils are found in the Laramie strata at a number of localities. They were observed in the beds exposed in the clay pit of the Minot Coal and Brick Company, one mile below Burlington, the fossiliferous beds which occur here being well toward the base of the formation; along the Missouri near Coal Harbor; in the bluffs of the Little Missouri at the Custer Trail Ranch, near Medora, and elsewhere.

The following fossils were collected from the Laramie strata.*

*Identified by Dr. T. W. Stanton of the United States Geological Survey.

Corbula mactriformis M. & H.
Viviparus trochiformis M. & H.
Goniobasis nebrascensis M. & H.
Unio sp. cf. *Unio priscus* M. & H.
Campeloma producta White.
Campeloma multilineata M. & H.

The first four species in the above list are from No. 62 of the Picket Butte section, five miles south of Medora, the bed containing them lying 230 feet above the Little Missouri. The last four were found at Coal Harbor at an elevation of eighty-five to 100 feet above the river.

At a number of points the Laramie contains abundant leaf impressions, among which the following have been identified:

Ten miles north of Minot;
Sequoia angustifolia Lesq.
Sequoia Langsdorfii (Brongniart) Heer.
Sequoia brevifolia Lesq.

Near Coal Harbor;
Credneria (?) daturaefolia.
Phyllites cupanioides Newberry.
Celastrus (probably).

The fossil leaves of the following species of trees were collected by Professor T. H. Macbride from the Laramie beds of the bad lands of the Little Missouri.*

Platanus nobilis Newberry.
Populus cuneata Newberry.
Juglans woodiana Heer.
Corylus grandifolia Newberry.
Carpinus betuloides Ung (?)
Persea (?)
Ficus (?)
Populus glandulifera Heer.
Cornus rhamnifolia O. Weber.

The Laramie formation has a very wide distribution throughout central North America and originally formed a continuous deposit about 2,000 miles long from north to south, with a width of more than 500 miles from east to west. It extends from Mexico far into Canada and is found on both sides of the Rocky Mountains. Their fossils show that the beds were, in large part at least, laid down in fresh water. Their origin is well set forth

*The Little Missouri Bad Lands; Pop. Sci. Mo. Vol. 22, 1883. pp. 634-642.

by White in the following paragraphs, taken from his correlation paper on the Cretaceous.*

"The Laramie sea is understood to have occupied a very large portion of the area which in the immediately preceding epoch was occupied by the marine waters in which the Montana formation was deposited, and that at its close the waters of the Laramie area became more or less completely surrounded by land resulting from an elevation of sea bottom above water level. Its waters consequently became partially freshened by the surrounding surface drainage, producing a habitat in which it was impossible for true marine forms to live, but which was a congenial one for those whose remains we find there. Thus was recorded a great physical, as well as a great biological, event in the geological history of the continent, our estimate of the importance of which is enhanced when we remember how great was the geographical area over which it occurred."

"It is reasonable to assume that the habitat of many of the vertebrate and other land animals which existed within and around that area before the event referred to occurred was not made uncongenial by its occurrence. But be that as it may, the strata which physically constitute such geological horizons as I have defined in this case are the result of sedimentation in great bodies of water, and physical changes which altered the conditions relating to those bodies of water and materially affected the character of their denizens, were leading events in geological history."

"By some persons the opinion has been held that during the Laramie epoch proper, open sea waters made occasional incursions at different places upon the area occupied by the nonmarine waters whose fauna characterizes the Laramie formation, but although the frequent alternation of strata bearing brackish water fossils with those bearing only fresh-water forms show that within certain districts brackish waters alternated with fresh, I have, in my extensive examinations of this for mation, never detected any evidence of the incursion of open sea waters. The opinion referred to, which I think has not yet been demonstrated, has perhaps arisen from a supposed identifieation of coal-bearing strata of the upper part of the Montana formation with similar coal-bearing strata of the Laramie. Because it is my present

*Bull. No. 82, U. S. Geological Survey, pp. 263, 152.

belief that all true marine waters were withdrawn from the interior portion of this continent at the beginning of the Laramie epoch, no true marine strata are in this memoir recognized as belonging to the Laramie formation."

"While I am not now prepared to admit that the open ocean made incursions upon the great Laramie inland sea after it had become established as such at the close of the Montana epoch, it is reasonable to infer that it had somewhere a more or less restricted outlet to oceanic waters until all the area which it had occupied became in part dry land and in part the bed of the great fresh water Tertiary lake or lakes which immediately succeeded it. What we now know of the various epeirogenic movements which resulted in the production of the present continent leads me to believe that such an outlet, if one existed, was at the southern end, and this suggestion is supported by certain paleontological conditions which have been observed in Laramie strata in the Texan and North Mexican regions. That is, certain fossil forms have been observed in those strata which seem to indicate a greater saltness of the water in which they were deposited than prevailed elsewhere in the Laramie sea; but these observations are too incomplete to be confidently relied upon in an inquiry of this kind."

TERTIARY

Strata younger than the Laramie and probably belonging to the Tertiary occur on top of Sentinel Butte, immediately overlying the sandstone. At the west end of this flat-topped butte is a low mound rising from twenty-five to thirty feet above the level surface. It is formed of a very light gray calcareous clay or marl with a faint greenish tinge, in which there are several thin layers of a nearly white limestone. Resting directly on the sandstone are eighteen feet of the light-colored marls and above these occur alternating layers of calcareous clay and limestone with a total thickness of seven feet. The latter is very fine-grained, brittle, compact, somewhat argillaceous, and a few of the beds contain much silica. The limestone is finely laminated and on exposure to the weather separates readily along the lamination plains into thin laminae less than one-sixteenth of an inch thick. The limestone layers vary from one-half to two inches in thickness and as previously stated are quite siliceous in places.

Fig. 1. Bluffs along the Little Missouri a few miles above Medora

Fig. 2. A butte on the Little Missouri, the river the foreground. Custer Trail ranch near Medora

The beds exposed in this mound are unlike any seen in the underlying Laramie formation and it seems not unlikely that they belong to the Tertiary. The apparent absence of fossils from these strata, however, makes it impossible to determine with certainty their age. Similar beds occur on top of the Slim Buttes and Cave Hills, not far south of the North Dakota boundary, and on account of their fossils are considered by Todd as of Miocene age.* From the close resemblance of the beds on Sentinel Butte to those farther south and from their similarity of position they are referred provisionally to the Miocene division of the Tertiary.

The level surface forming the top of the butte is thickly strewn with angular fragments of chalcedony. These are extremely abundant and in many places form a stony pavement several inches thick. Their angular and irregular shapes suggest that they were formed as siliceous nodules or veins in an overlying formation which has been removed by erosion. The beds in which the chalcedony formerly occurred have been removed, leaving that mineral behind. The action of frost, changes of temperature, and other agencies have caused the nodules and vein material to be broken up and reduced them to angular fragments.

Todd states that "flat pieces of chalcedony, which have come from the veins of the Tertiary beds" are abundant in western South Dakota.†

PLEISTOCENE FORMATIONS

Drift.—The larger part of North Dakota is covered to a greater or less depth by a peculiar deposit known as glacial drift. It is very different in appearance and origin from the geological formations previously described and forms a mantle which buries from view the older rocks. The drift is composed of clay, sand, gravel and boulders mingled together to form a heterogeneous deposit. The chief constituent is a stiff blue or gray clay through which are scattered numerous pebbles and boulders of granite or other igneous rock. It is commonly known as boulder clay or till and nearly all of the boulders and smaller rocks differ from the underlying strata, having been transported from distant localities where ledges of such rock occur. Another

*South Dakota Geological Survey, Bull. No. 2, p. 62.
†South Dakota Geological Survey, Bull. No. 1, p. 121.

peculiarity of the pebbles and boulders of the drift is that many are smoothed, polished and scratched on one or more sides.

The question naturally arises as to the origin of the drift, and a brief discussion of this will be in order here. It was formed by a continental ice sheet or glacier which once covered the northern part of North America just as Greenland and the Antarctic regions are today covered by vast ice caps. This glacier extended as far south as Long Island, the Ohio river at Cincinnati, and the Missouri river, in Missouri. It entered eastern Kansas and Nebraska, South Dakota, and covered all of North Dakota except several counties in the southwestern corner. The drift represents the materials that were gathered up by the ice sheet as it advanced over the land, were accumulated beneath the ice, and were left behind when it melted. The foreign boulders and pebbles of the drift have been transported from the north and left, often hundreds of miles from their source. Most of the granite boulders of this state have been brought from Canada in this manner. The polished and scratched faces found on so many of them, particularly the smaller ones, were formed when the rock fragments were frozen in the bottom of the ice and were carried along between the heavy ice sheet and its rocky bed, wearing down, smoothing and striating both the pebbles and the rock bed over which they passed.

Recent studies of the drift in the United States have disclosed the fact that there are not one but several distinct sheets of drift, produced by different ice invasions. For many years it has been known that there was an older and a younger drift and investigations in the Mississippi valley region, particularly in Iowa, have established the presence of five separate and distinct drift sheets. Beginning with the first and oldest these have been named the Albertan or pre-Kansan, Kansan, Illinoian, Iowan and Wisconsin drift formations. Between the deposition of these various sheets the ice retreated for a time and these interglacial intervals are marked by vegetable accumulations representing ancient forests and soils, often many feet in thickness, and by heavy deposits of gravel and sand laid down by the streams flowing from the melting ice.

Considerably more than half of North Dakota is covered by the youngest of the drift sheets, the Wisconsin, whose border is marked by a conspicuous belt of irregular hills and hollows ten to fifteen miles wide, constituting the Altamont moraine, as it is

called. This was formed along the edge of the ice where it remained stationary for a time, the rock debris carried by the glacier being accumulated and heaped up into the morainal drift hills, which are often dotted with numerous large boulders. This moraine has been traced across the state from north to south; it traverses Ward county, from northwest to southeast, about thirty-five miles west of Minot keeps the same direction through McLean county, turns south through eastern Burleigh county, crosses northeastern Emmons and after making a loop to the east into Logan and McIntosh counties again enters the southeastern corner of Emmons, whence it continues into South Dakota. The Northern Pacific crosses the Altamont moraine between Driscoll and Sterling.

Lying west of the moraine is an older drift sheet which has been regarded as the Kansan. There is, however, reason to doubt whether it is as old as the Kansan, since it has few or none of the characteristics of that drift sheet as found in other states, having every appearance of being much more recent. It is quite fresh and unweathered, is light gray in color where exposed in railroad cuts and elsewhere, and its surface has undergone very little erosion, being poorly drained in many places and containing many lakes. The pebbles of granite and other ignious rock are noticeably fresh, rotted and decomposed pebbles being very rare. In all these respects this extra-morainal drift is strikingly different from the typical Kansan. It is possible, however, that this difference is due to the semi-arid climate of the region, the weathering effect on the drift of the dry atmosphere being much less than farther south in Iowa, Kansas, and other states where there is much more moisture.

Yet it may be that this drift is younger than the Kansan, as it has every appearance of being, and it is perhaps an earlier Wisconsin drift than that occurring within the Altamont moraine. More work will be required, however, before the age of this extra-morainal drift can be fully determined.

This glacial deposit is not bordered by any terminal moraine but thins out toward the edge so that the boundary is not well defined. So far as our present knowledge goes this older drift sheet extends from thirty to fifty miles or more west and south of the Missouri river. Over much of the area beyond the river it is thin and has modified but slightly the preglacial topography.

The thickness of these glacial deposits varies within wide limits, being all the way from a few feet to several hundred feet. In the eastern part of the state it is shown by wells to be commonly from 200 to to 300 feet thick, and it is probable that these figures also apply to the central part of the region. Wells pass through 220 feet of drift at Fargo, 250 at Casselton, 310 feet near Grandin and Kelso and 298 feet at Grafton.* The Grand Forks well penetrated 380 of drift and lacustrine deposits before reaching bed rock.

Both the older and newer drift sheets are exposed at numerous points throughout the state. Perhaps the best exposures are found in cuts along the railroads, such as those west of Minot along the Great Northern, or on the Northern Pacific between Driscoll and Sterling, where the railroad crosses the Altamont moraine.

Lacustrine Deposits.—Deposits laid down in extensive lakes which once covered large areas in North Dakota also deserve notice in any discussion of the geological formations of the state. The remarkably fertile lands of the Red River valley are formed of sediment which was deposited in old glacial Lake Agassiz. This vast body of water formerly covered eastern North Dakota, northwestern Minnesota and a large portion of Manitoba, having an area of 110,000 square miles, or more than the combined area of the Great Lakes. The streams emptying into Lake Agassiz were loaded with sediment which was laid down over the floor of the lake to form the sandy clay or loam which overlies the thick drift sheet of the Red River valley. Similar lacustrine deposits are found south and west of the Turtle Mountains, having been formed in another smaller glacial lake, known as Lake Souris, which once occupied that region. It extended west and south as far as Minot and Velva, east as far as Rugby and north across the international boundary in Manitoba, covering the larger part of Bottineau and McHenry, and adjoining portions of Rolette, Pierce and Ward counties. Deposits of like origin but of less extent occur in the southeastern part of the state.

Alluvial Deposits and River Terraces.—Among the most recent formations are the alluvium and gravel terraces found along most of the streams, particularly the Missouri. The alluvium occurs

*Upham, Mons. No. XXV, United States Geological Survey.

on the lowlands or flood plains forming the bottoms of the valleys and is seldom more than twenty to thirty feet above the river level. The deposit consists of sand or clay, or a mixture of the two, and represents the sediment laid down by the streams in time of flood. All of the important rivers of the state have developed flood plains varying in width from a fraction of a mile to several miles and formed of alluvium, which constitutes the rich soil of these bottom lands.

Of similar origin are the gravel terraces bordering most of the streams and lying from twenty-five or thirty to one hundred feet above the water. On the Heart river, a few miles west of Mandan, the James at Jamestown and the Sheyenne at Valley City, extensive gravel pits have been opened in these deposits and the material removed for railroad ballast. These gravel terraces represent the remnants of former flood plains which have been left at their present elevations by the down cutting of the rivers, the latter having eroded their channels to a greater or less depth below the level at which they once flowed. At the time of the melting of the ice sheet the streams flowing from it carried great quantities of gravel and sand which they deposited along their courses, building up the floors of their valleys and forming broad flood plains. Subsequently when the supply of sediment was reduced these rivers began to lower their channels in the flood plains and the latter remain as terraces.

STREAM MEASUREMENT AND RUN-OFF OF STREAMS IN NORTH DAKOTA

By

E. F. CHANDLER

METHODS OF STREAM MEASUREMENT

Accurate or even rough measurements of the water flowing in rivers, creeks, and other streams are very infrequent in comparison with measurements of the land that borders the streams. The most definite call for land measurements arises for the purpose of fixing the price of this real property, yet at all times there is in the owner's mind a fairly precise idea of the magnitude of his possessions, and he has at least approximate methods of measurement whereby he can estimate the area of each portion of his farm; he will tell you how many acres have been plowed, how much has been seeded for each crop, and so on, as long as desired. It is a necessity if he would carry on his work intelligently and to advantage. He can probably at a single glance estimate within twenty-five per cent the area of a field or tract that falls under his eye.

If, however, he were called upon some day to estimate the amount of water flowing in a creek passing across his farm, he might find himself unable to fix a figure that was not ten times larger or smaller than the facts. Any estimate that might be desired concerning the length of time it would occupy for the stream to fill some proposed tank or reservoir would find him entirely at a loss. He would hardly know whether to say five minutes or five weeks. There are so many factors to take into consideration that the task seems difficult. "The operations of measuring the volume of a flowing stream, although not complicated, possess an element of mystery to the average citizen, largely because he has not been accustomed to consider fluctuating quantities. It is possible to form a very definite conception of the amount of water standing in a pond or reservoir, but in the case of a stream the quantities considered are of water in motion, and therefore another and somewhat novel element enters, that of time."*

The width of the stream must be noted, and this, especially for a large stream, is not readily done by a person accustomed to walking on the dry land; appearances deceive him. The depth

*F. H. Newell, Irrigation in the United States, Chapter 3.

must be known, and here again appearances are often misleading. If the stream be shallow a small error in estimate of depth leads to disproportionately large errors in the result. In the muddy streams of North Dakota, small or great, it is rarely that the eye is a guide. Lastly the speed of the stream need be known; and here great uncertainty again arises in the observer's mind; even if there were mile-posts along the bank, floating objects move so irregularly, now speeding down the center of the channel, now lingering in an eddy or lodging on the bank, that no definite result seems readily attainable.

These difficulties arise, however, in part from lack of experience, from never having given any consideration to methods of measurement. Land is real property, to be definitely measured and individually owned and to be the chief part of one's wealth. But water, even if hardly "free as air", was classed with the rain that falls alike on the just and the unjust, a boon to which no one man can acquire title; its ownership or sale being unusual; its measurement seemed unnecessary and methods were scarcely developed until recently.

"It is to furnish information upon which to base estimates of available water supply that the Hydrographic Division of the United States Geological Survey has been, during the last fourteen years, collecting data in regard to the flow of the rivers in the United States, and their variation from season to season and throughout a series of years. The necessity for such data is frequently brought to the attention of the engineer, sometimes in a most startling manner. The lack of this information frequently leads to the most disastrous mistakes in the construction of hydraulic works. One of the best examples of this in the design of a hydraulic plant was the construction of a dam and water-power plant at Austin, Tex. After an expenditure of $1,600,000 it was found that a grave mistake has been made in the low-water flow. The works were constructed by the city in accordance with a vote of the citizens of Austin in 1890. It was estimated that 14,000 horsepower could be developed, and the people felt that their city was to become a great manufacturing center. No hydrographic data had been collected, except from the hazy memory of the "oldest inhabitant." In the spring of 1890 a measurement of flow giving 1,000 cubic feet per second was taken as the minimum. This estimate was more than five times too great, as was shown by subsequent measurements. An error

of 500 per cent had been made in the estimate, but this was not ascertained until the works were nearly completed.

Mistakes of this kind have occurred in every part of the country in hydraulic works. The Sweetwater dam in California is a good example of a project carried through on insufficient data. The dam was built after a series of wet years and was soon after filled to overflowing, so that increased spillways were constructed, but since that time the water in the reservoirs has never reached an elevation near the crest of the spillways, and during most of the time there has been the greatest scarcity of water.

The Bear Valley dam is a more marked case, as the reservoir formed by the dam has been practically dry for several years, so that wells have been driven in the bottom of it.

The Gila Bend, Arizona, project is another example of the expenditure of a large sum—$900,000—upon insufficient data, and subsequent abandonment of the scheme. In this project the dam was carried away before its completion, but if it had been completed the scheme must have proved a financial failure.

Many diversion canal projects for irrigation have been either partial or complete failures on account of shortage of water; that is, developments have been made far beyond the capacity of the stream.

A great number of waterpower plants have been constructed upon insufficient data, and later, auxiliary steam has been found necessary. Allowance was not made in the original estimates, so that in a number of instances the project has been found unprofitable. Knowledge of the flood flow is also of great importance in designing the dams and waste ways.

The measurement of the larger streams of the United States is an important undertaking, and capital will be invested in power developments, irrigation, sanitary and other hydraulic works more freely when information as to the flow of the streams is available. In making measurements of streams it is of course desirable that rapid and economical methods be used, if such are of sufficient accuracy." *

The usual methods will be outlined here, with special attention to the simpler methods that are readily available for use by the man without special technical training, without elaborate instruments or long computations, if he desires to obtain a basis for rough estimates of stream flow for any use; if, for example,

*H. A. Pressey: Observation on the flow of rivers in the vicinity of New York City.

it is desired to know whether some spring or creek can possibly irrigate a whole township or whether it is absurd to consider it as a means for irrigating more than a garden-patch.

There are three methods of measurement in general use: first, by current-meter; second, by weir; third, by floats.

The first and most elaborate method, by current-meter, is the one used customarily by the United States Geological Survey, but is not convenient except for those regularly employed in the business of stream measurements. The current-meter is an instrument which measures the velocity of the water by means of a wheel that is lowered into the water and revolved by the current. This wheel may be shaped like the screw propeller of a steamship, or like the wheel of an ordinary windmill, but in the most approved form consists of several cups arranged on the circumference of a circle about six inches in diameter, all opening in the same direction around the circumference. When placed horizontally in the water, this wheel (like the ordinary form of whirling cup anemometer for measuring the speed of the wind,) is revolved by the current catching in the interior of the cups and is turned with a speed very nearly proportional to the velocity of the current. This relation is accurately determined for all the various patterns of meter, (each turn of the wheel indicating from two to five feet flow of water, according to the size and form of the wheel) so that from a count of the revolutions of the wheel the speed of the current is definitely known. Suitable weights and rudder-vanes are attached for sinking the meter into the stream and holding it steady, and an electric connection or other means is used to indicate to the person operating it how many revolutions are made.

The speed of flow of a stream is not everywhere the same, but it is least at the bottom, and greater near the surface. At mid-depth the velocity will evidently be nearly the average for the whole channel, but is found to be slightly greater than the average except in very shallow channels. In an ordinary unobstructed channel the average velocity will be found at about six-tenths of the whole depth below the surface, or in deep smooth flumes at two-thirds the whole depth.

A suitable place for the use of meter is selected, where the current is without eddies, fairly uniform, and as nearly as may be of an even speed from one side of the stream to the other, preferably on a straight stretch, and necessarily where the chan-

nel has a reasonably even cross section (width and depth) for some little distance and is not obstructed by rocks, logs, brush, or vegetation. At a favorable place in the middle of this stretch the measurement is made on a line perpendicularly across the stream by measuring width, depth, and velocity. The measurements of depth are made with sounding-pole or sounding-line at ten or twenty points (or more on a large river) at equal distances along the line. The area of the cross-section of the stream at this line is thus closely determined. The velocity is of course different at different points in the width. Therefore in order to obtain a reasonably correct result the cross-section is divided

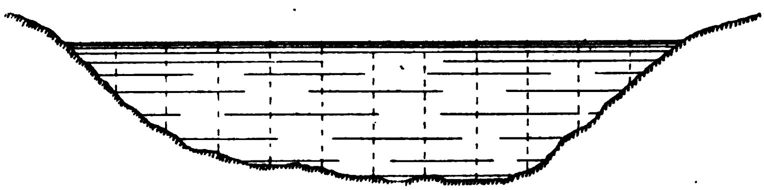

Fig. 5

into ten or more smaller sections (most conveniently of uniform width) by imaginary vertical lines, as shown in Figure 5, each of these being approximately a trapezoid (or rectangle, or at the margin, a triangle) whose area can be readily computed from the soundings. These small sections are taken narrow enough so that, if the velocity is different at the sides of a small section, the velocity at the middle point of the width of each may nevertheless be assumed to be a fair average. The velocity at the middle of each small section is then measured with the meter; when this velocity is multiplied by the area of the small section, the flow through that section is obtained; and then, by adding the flow of all the small sections together, the total flow of the stream is found.

Using the foot as unit of length and depth, the area of the cross-section will be given in square feet; using a speed of one foot per second as the unit of velocity of flow, the product of the cross-section and the velocity will give as a result the total number of cubic feet of water flowing by the observer each second, or the number of "second-feet", as the term is. For example, the statement that the flow of a stream is six second-feet does not indicate anything concerning the dimensions of its channel or the velocity of its current, but merely says that six cubic feet of water is discharged each second. The channel might be one foot

wide and one foot deep with a current speed of six feet a second, or six feet wide and two feet deep with a current speed of one-half foot per second, or three feet wide and one foot deep with a current speed of two feet a second, or in any other ratio giving the same total product. The total flow will of course be the same, whether measured at a narrow, contracted point of large velocity or at a point where the current is wide, deep and sluggish.

This method is applicable to streams of any size from the largest rivers down, except very small ditches and brooks, and gives reasonably accurate results (with an error rarely as much as five per cent) if the stream is flowing in a good straight channel with even and unobstructed flow. It may be used from a bridge, from a small car running on a cable stretched across the river, from a boat, or in a small stream by wading, provided in these last cases that some means is used for holding the meter upstream from the observer, so that it will not be effected by the eddies caused by his feet or by the boat.

This method of measurement can be accurately employed on any artificial channel of appropriate form, such as a ditch or canal, if the speed is sufficient to turn the meter-wheel freely. If the channel is a timber flume or other form not liable to be changed, eroded or obstructed, a careful determination can be made once for all of the quantities of water flowing for various depths in the flume. In large irrigation canals it is a frequent custom to install rating flumes, timber-lined sections of a few rods in length; the side of such a flume is marked at each possible height of water surface with a number indicating the quantity of water flowing when the water rises to that height in the flume. It is then an easy matter for the ditch-rider or gate-tender to keep a continuous daily record of the total flow.

In a natural channel, if there are no dams or other obstructions for a considerable distance below the point of measurement and if other conditions are suitable, it will be found that the same amount of water flowing causes always almost the same height of water-surface in the channel, so that, after a series of such measurements of second-feet discharge at different stages of water, a rating-table can be prepared showing with fair precision (say within five per cent) the probable flow for any height of water. It is such representative points that the United States Geological Survey selects for the location of gauging stations. At these stations a vertical gauge rod painted in feet and frac-

tions is placed in the water at a bridge pier or at the river margin, or other suitable device is installed, by means of which the height of the water surface may be accurately seen and recorded daily by a local observer. These observations are reported regularly to a district hydrographer who visits the stations from time to time to take soundings, velocity measurements, etc., for the purpose of finding the amount of flow corresponding to different heights of water on the gauge, and thus finally computing the total amount of water flowing down the stream in a year, and the greatest, least, and average flow for each month.

The United States Geological Survey has commenced in this state, chiefly within the past two years, since popular interest in irrigation has arisen here, a comprehensive system of stream measurements of this nature, gauging stations having been established on all the principal streams. At present one of the faculty of the University of North Dakota is the engineer in immediate charge of that branch of work for North Dakota and Minnesota.

The second, or weir-measurement, method affords still more accurate results when the conditions are favorable. A weir is a dam or small barrier with level crest over which the water flows. The depth of water on the crest evidently will be greater for a greater flow, and experiment has shown that the relation between

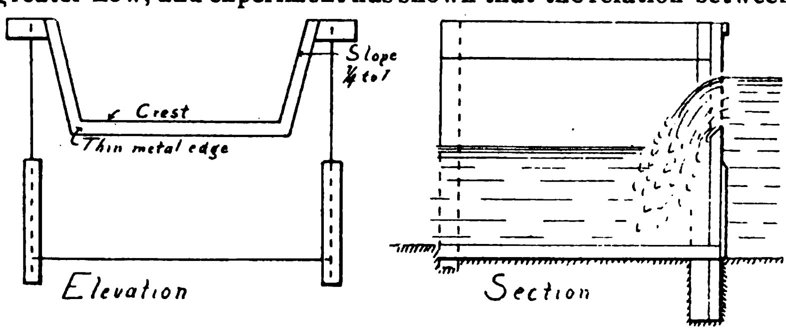

Fig. 6.

them can be stated in definite figures if the weir is properly constructed. There are two forms of weir most frequently used, although special circumstances sometimes make other forms more convenient. The rectangular weir has vertical ends; the trapezoidal or Cippoletti weir, as shown in the illustrations (figures 6,

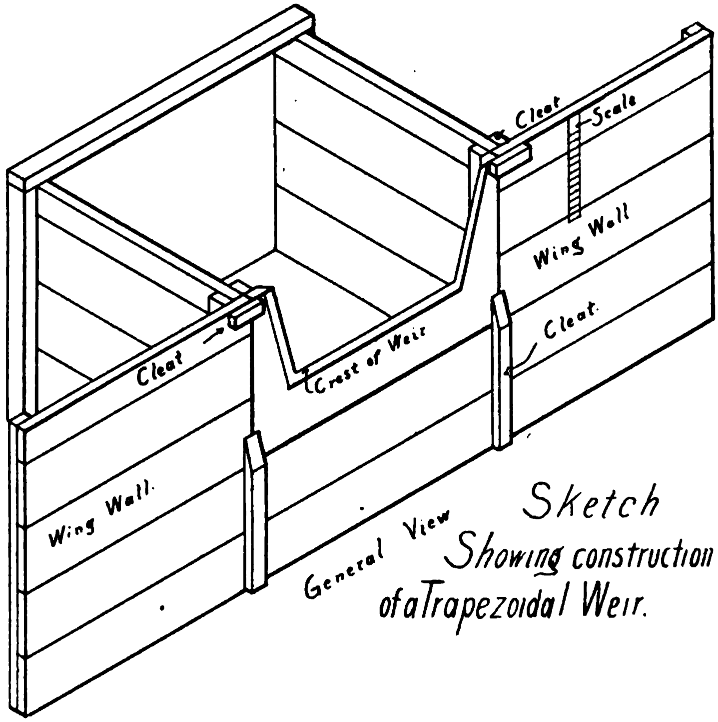

Fig. 7.

7, and 8) widens above the crest, each end sloping outward one inch in every four inches rise; the second pattern has the simpler formula for computation of flow.

In using the ordinary weir, it should be placed in the middle of the channel at right angles to the stream with its up-stream face in a vertical plane. The crest should be chamfered so as to slope downward on the lower side with an angle of not less than thirty degrees, leaving a sharp edge over which the water can leap freely without retardation by friction, or better still a stiff sheet of thin metal may be placed vertically to form the edge, and the ends should be chamfered likewise. The air thus

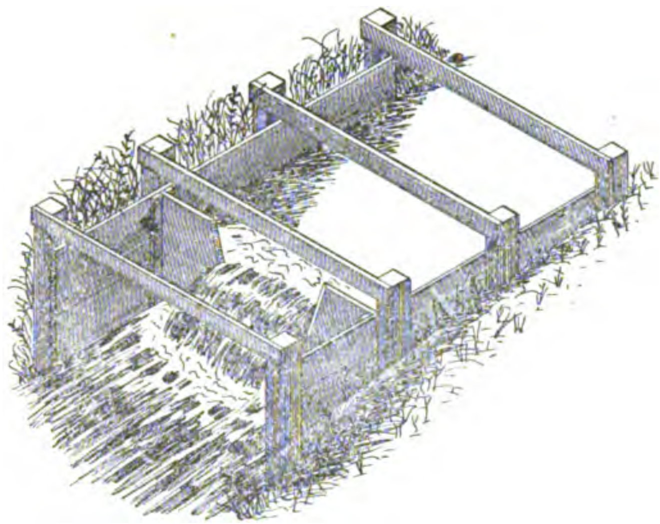

Fig. 8.

has free access under the falling water. In the pond caused by the weir, the water will be brought nearly to rest, and must approach the crest evenly and without cross-currents; this requires that the approaching channel should be straight and even and be at the weir more than twice the depth and at least three times the width of the jet passing over. The length of the weir opening should be three or four times the depth of the jet at the time of the greatest flow.

If the length of the crest of the weir, L, and the depth of water on (or rather, height of the water surface above) the crest, H, be measured in feet and decimals of a foot, the number, Q, of cubic feet of water per second flowing over a rectangular weir can be computed from this formula,

$$Q=3.33\ (L-0.2\,H)H\sqrt{H}$$

and over a Cippoletti weir

$$Q=3.37\ L\ H\ \sqrt{H}$$

The height above the crest of the weir of the level water-surface a few feet behind the weir may be readily found without level or other instrument thus: When the water is first filling

the channel behind the weir, if a stake be driven in the water with attention that the top of the stake be exactly at the water surface at the instant that the water begins to flow over the crest, the subsequent depths of water over the top of this stake will be the required heights.

The formula for the flow is not a complicated one, and for a trapezoidal weir may be expressed in words, "multiply the square root of the depth above the crest by three and three-eighths times the product of the depth and the length of the crest, all being expressed in feet and decimals." But tables are prepared for all the standard sizes of weirs, and may be prepared for any with a few hours work, that give at a glance the amount of flow for each depth of water.

Convenient dimensions for weirs according to the expected amount of flow are given in this table:

For a discharge less than two-thirds second-foot make crest of weir one foot long.

For a discharge between two-thirds and two second-feet make crest of weir one and one-half feet long.

For a discharge between two and four second-feet make crest of weir two feet long.

For a discharge between four and ten second-feet make crest of weir three feet long.

For a discharge between ten and twenty second-feet make crest of weir four feet long.

For a discharge between twenty and forty second-feet make crest of weir five feet long.

Weirs are advantageous for use in canals and ditches whereever sufficient fall can be afforded so that the water leaps freely over the crest without interference from backwater. They are often placed permanently in such cases, for variation in the amount of water flowing in a canal while in use is not great, hence the weir may be small enough to measure accurately the minimum flow, and yet be able to carry the greatest usual flow. In a natural stream, and especially in small streams, the seasonal variations are likely to be greater, and therefore any particular weir will be available for use only at certain stages; while on large streams the cost of constructing a weir would be disproportionately great. Sometimes there are water-power dams on such streams that have level crests and are otherwise so constructed as to permit such measurements; for, although they are not usually sharp-crested as required above, there are suitable form-

ulas, similar to the preceding, giving the flow over wide-crested weirs and other forms.

In a small stream the summer low water flow may be determined without difficulty by making a weir of a few planks and placing it in the top of a small temporary dam of stones and turf, but this will of course be destroyed by the first flood.

One of the earliest units of water measurement was the "miner's inch," a unit of simple application which was measured in a similar fashion. According to Colorado statute, a miner's inch is defined as the quantity of water delivered through an inch-square orifice, under a five inch pressure measured from the top of the orifice to the surface of the water, in a box set in the banks of the ditch. It would evidently be inconvenient to measure large quantities of water by this unit, nor is it an accurate and definite unit, for a change in the shape of the orifice will change much the amount of water delivered, therefore its use is being abandoned. It is variously defined in different states, but a statement now accepted in many regions is the ratio that one second-foot equals fifty miner's inches.

The float-measurement method, though not giving accurate results, is quite simple and is fairly good if there is no strong wind or other such disturbing factor, and if on the stream a suitable straight portion with smooth, even current can be found. By stretching cords or wires across or by setting range poles on the opposite shores, two parallel lines are marked perpendicularly across the stream so as to include a convenient portion of the channel from ten feet to five hundred feet long according to the size and character of the stream, speed of current, etc. The width is measured and soundings with line or rod are made at numerous points across the width so as to give the average depth and therefore the area of the cross-section. This should be done under each of the parallel lines, and also if the stretch between them is long at one or two lines intermediate between them. Floats of some sort are then thrown singly into the stream above the upper line, the time each passes the upper line precisely noted, and the time it passes the lower line. If the total distance between the lines (in feet) be now divided by the time in seconds occupied by each float in passing down that distance its velocity in feet per second is found.

The average velocity of the stream may be assumed to be from four-fifths to eleven-twelfths of the surface velocity, according

to wind, character of channel, etc. For a large stream in an unobstructed channel with smooth mud or sand bottom, the average velocity is likely to be nearly nine-tenths of the surface velocity; but in a smaller stream with bottom of pebbles and small stones the average may not be more than five-sixths the surface velocity. Also a wind if down stream of course increases the surface velocity and if upstream decreases it.

The floats may be sticks and chips or anything else convenient, but must be as nearly submerged as possible, especially if the current is sluggish, to avoid catching the wind. Bottles tightly corked after being partially filled with water so as to be almost submerged are good in a river.

Other more elaborate floats, such as rods weighted so as to float vertically, extending nearly to the bottom of the channel, or double floats with a weighted vane in the lower portion of the stream hanging by a cord from the visible float at the surface are sometimes employed, with the intention of obtaining directly the average velocity; but their use is as troublesome as the employment of the more accurate current-meter.

On a large stream this work requires several persons, but one person alone can obtain after a little practice fairly good results on a small stream, especially if a cheap stop-watch is used for timing. The computation of a float measurement may be made by several methods. Most simply, after floats have been timed along every part of the width the velocity given by each float may be found, their average taken as the average velocity of the stream, and the cross-section of the stream multiplied by the average velocity to obtain the flow. If the stream is of considerably different depth in different portions of the width, quite large errors may enter unless more floats are taken in the deeper portions, somewhat in proportion to the depths. Note that the velocities should be averaged, not the times of floating down, in order to avoid giving undue weight to any float that happened to be delayed in the edge of the stream. This method is fairly satisfactory for a small brook, and is illustrated by this example:

Float measurement of Little Muddy river twenty-five miles north of Williston, September 14, 1904:

Length taken for run of floats, 20 feet.

Average width, 5 feet 6 inches.

Depths (taken at equal intervals on four lines across stream):

1, 2, 2, 3, 2 inches.
1, 1, 2, 2, 1 inches.
1, 2, 3, 2, 1 inches.
2, 2, 3, 1, 1 inches.

Therefore the average depth is 1.75 inches or 0.146 feet.

Depth multiplied by width gives area of cross-section, 0.80 square feet.

Number of seconds taken by floats in running 20 feet: 13, 11, 9, 10, 8, 10, 13, 12, 12, 22, 8, 10, 9, 11, 9 seconds.

Length of run divided by time gives speed of each float in feet per second: 1.54, 1.82, 2.22, 2.00, 2.50, 2.00, 1.54, 1.67, 1.67, 0.91, 2.50, 2.00, 2.22, 1.82, 2.22. Average surface velocity, 1.98.

Slight wind downstream; if total average velocity is taken as four-fifths of surface velocity, four-fifths of 1.98 is 1.58.

Area of cross-section multiplied by velocity gives total flow; 0.80 multiplied by 1.58; total flow, 1.26 cubic feet per second.

A better method is to imagine the stream divided (as detailed under the description of the current-meter method) into sections of narrower width, say one foot, two feet, five feet or ten feet, and to run several floats in each small section, from the velocity of which with the measurements of depth the amount of flow through each small portion of the whole cross-section may be separately computed, and the total flow obtained by adding these.

This method is illustrated by the following example:

Float measurement of Knife River, ten miles above mouth, August 26, 1904—whole width, thirty-two feet, divided into sections four feet wide. Depths taken and floats run through middle of each section. Length of run, fifty feet.

Distance from right bank—feet	Depth at upper line—feet	Depth at lower line—feet	Average depth—feet	Width of section—feet	Area of each section—square feet	Average time of floats—seconds	Surface velocity—feet per second	Discharge of each section—cubic feet per second
2	0.4	0.6	0.5	4	2.0	193	0.26	0.52
6	0.9	0.9	0.9	4	3.6	108	0.46	1.66
10	1.3	1.1	1.2	4	4.8	46	1.09	5.23
14	1.6	1.4	1.5	4	6.0	39	1.28	7.68
18	1.4	1.2	1.3	4	5.2	34	1.47	7.61
22	1.2	1.2	1.2	4	4.8	41	1.22	5.86
26	1.0	1.2	1.1	4	4.4	62	0.81	3.56
30	0.9	0.9	0.9	4	3.6	235	0.21	0.76
Total discharge								32.91

No wind. If average velocity is taken as seven-eighths of surface velocity, seven-eighths of 32.91 is the total flow, 28.80 cubic feet per second.

(NOTE. The distances, depths, and times are found in the measurement, and the other columns filled in the computation. Area of section multiplied by velocity equals discharge).

Several units for water-measurement are frequent. The one used above is the "second-foot" which means a flow of one cubic foot each second, and is the most convenient unit. Gallons per minute or per day are often used, especially in connection with city water supply. One second-foot is equal to about 7½ gallons per second, 450 gallons per minute, or 650,000 gallons per day, which affords much larger and more impressive figures for presentation to the tax-payers who are meeting the expenses of the pumping plant. The "miner's inch," or merely "inch," is another unit, of rather indefinite value as described above. The most frequent unit for measurement of water stored in reservoirs is the acre-foot, a quantity of water sufficient to cover one acre a foot deep. A flow of one second-foot will amount to almost two acre-feet per day.

If it is prospective use for irrigation that gives value to the stream, after a measurement of the amount of flowing water has been made the next question that arises is "How much land will this stream irrigate?" This leads to a discussion of the duty of water. The duty of water, as the ratio between the number of units of land and of water properly to be applied to it is called, is not everywhere the same, but depends upon the climate, upon the character of the soil tilled, and upon the nature of the crops cultivated; experience will bring more definite knowledge concerning the needs of the land in this state. But as a conservative estimate the general statement may be made that eighty acres may be irrigated with one second-foot of water. In most of the western states some such figure is set as the legal duty of water, that is to say as the amount of water that the owner of any particular tract of land is not entitled to exceed in his claims.

Another phrase which is especially convenient in deciding how much land a storage tank or reservoir full of water will irrigate is the the statement, as yet tentatively made, that in North Dakota two acre-feet of irrigation-water to each acre of land per year should be sufficient for most crops, i. e., enough water to cover the land two feet deep if none of it were soaking in or running off. It may be noted that a continuous flow of one cubic foot per second would cover eighty acres two feet deep in about eighty days; so that, assuming an irrigating season of eighty days, the phrases above would have the same value.

Whatever quantity of water is assumed as needed, be it a flow continuously during the irrigation season of one second-foot for

each eighty acres or an amount sufficient to cover the land two feet deep or more, or less, an approximate knowledge of the amount of water available for use is the prime essential, and it will be found that with a very little practice this can be at least roughly obtained by some of these methods. A few such measurements at high water, medium stages and low water on any stream will prove very helpful if its use for irrigation or any other purpose is contemplated. Advice or assistance in any difficulties arising in such measurements will be freely offered in reply to any letter of inquiry sent either to the State Irrigation Engineer or to the State Geological Survey, at the post-office, University, N. D.

THE RUN-OFF OF THE STREAMS IN NORTH DAKOTA

An interesting problem in local geology or physical geography is the relation between the rainfall of any region and the run-off of its streams. This is not a problem that can be solved from studies in a single locality and a constant ratio found once for all between the depth of the rainfall and the quantity of water flowing away in the streams; the ratio varies in different regions, in different seasons, and in years of unusually large or small rainfall. Even in a single state there are large variations if regions of as great dissimilarity in topography as the extremes of North Dakota are included.

A study of the records of the stream-gauging stations that the U. S. Geological Survey maintains in the state, which records are briefly summarized in the following pages, and a study of the diagrams for graphic illustration, bring to view many interesting facts concerning this problem, a few of which may appropriately be noted here.

"The waters of the earth are taken up by the process which we call evaporation and formed into clouds, to be again precipitated to earth in the form of rain or snow. Of the water which falls upon the basin of a stream, a portion is evaporated directly by the sun; another large portion is taken up by plant growth and mostly transpired in vapor; still another portion, large in winter but very small in summer, finds its way over the surface directly into the stream, forming surface or flood flows; finally, another part sinks into the ground, to replenish the great reservoir from which plants are fed and stream flows maintained during the periods of slight rainfall, for the rainfall is frequently,

for months together, much less than the combined demands of evaporation, plant growth, and stream flow. These demands are inexorable, and it is the ground storage which is called upon to supply them when rain fails to do so.

All of these ways of disposing of the rain which falls upon the earth may be classed as either evaporation or stream flow. Evaporation we make to include direct evaporation from the surface of the earth, or from water surfaces, and also the water taken up by vegetation, most of which is transpired as vapor, but a portion of which is taken permanently into the organisms of the plants. Stream flow includes the water which passes directly over the surface to the stream, and also that which is temporarily absorbed by the earth to be slowly discharged into the streams.*"

If the rainfall is measured at well distributed points, so that the average rainfall over the basin of any stream is known, and if the records of the quantity flowing down the stream are kept, the ratio between the evaporation and the stream flow, or rather between the total rainfall and the portion that escapes evaporation and runs off, is at once known for that season.

North Dakota falls within three principal drainage areas as follows:

The Hudson Bay drainage area. Hudson Bay receives the waters from the Red river and its tributaries, the principal of which are the Mouse, the Pembina, and the Sheyenne, and (from Minnesota) the Red Lake. This includes the eastern side of the state and portions of the northwestern and central regions.

The Devils Lake drainage area. This interior basin which has no outlet receives the small streams from the middle northern section of the state.

The Missouri River drainage area includes, roughly speaking, that half of the state cut off by a diagonal from the southeast to northwest corners. The principal tributaries of the Missouri are, on the east side the James, on the west side the Little Missouri, Knife, Heart, and Cannon Ball.

The Red river is the largest stream in the state except the Missouri. The fall of its main valley is small, only about one foot per mile. It is the boundary between North Dakota and Minnesota and during most of the year receives its main supply from the Minnesota side, where the rainfall is somewhat greater

*U. S. Geological Survey, Water Supply Paper, No. 80, by Geo. W. Rafter.

and therefore the surplus running off unevaporated is much greater and where the forests protect the water upon the surface and in the soil from the wind and from evaporation, so that the residue running off is greater; they also hold back the water of the spring and of the storms, giving a more constant perennial flow.

The Red river itself rises in Otter Tail and other lakes in Minnesota and curving southwest reaches the North Dakota boundary at Wahpeton. At Fargo the Sheyenne enters it from the west, and although the area which the Sheyenne has drained is slightly greater than that of the Red, its average flow is scarcely more than half as great.

The Red Lake river comes direct from the lakes and woods in northern Minnesota, entering the Red at Grand Forks; though the area it drains is less than three-tenths the drainage area of the Red above Grand Forks, (and is not as large as that of the Sheyenne) its flow is nearly as great as that of the Red river, and in summer is much greater, so that from thirty to sixty per cent of the water below Grand Forks comes from the Red Lake river. Its flow is from ten to twenty times that of the Sheyenne, except for a brief time in the spring.

The Red river is peculiar among the streams of the United States in that it flows north, and before the ice has broken on its lower reaches the spring thaws are in force in the upper valley and all the coulees and streams bank full. Hence the ice carried down from the upper part does not find clear passage and jams and high water are likely

The high water of 1897 is the highest recorded, coming at Grand Forks within a foot of the level of the pavements of the city streets in most of the city. In 1904 so extreme a height was not reached by almost ten feet, but the duration of high water was much longer, the water being within six feet of its highest mark this season for twenty-five days.

All the streams in this area are usually deliberate in their actions on account of their small fall; there are no sudden changes in height nor in the streams fed from the forests of Minnesota are there great extremes in flow. The difference between maximum and minimum is seen to be comparatively small for any month except sometimes in the early spring. The Sheyenne has a fall of only about three feet per mile of valley. The Red river, with its much less fall would degenerate into a mere slough,

choked with vegetation, were it not for the large amount of water that it carries. This is the case with the James, whose fall is about two feet per mile, and in a dry season its summer flow is only ten or twenty second-feet or less, insufficient to keep its channel clear.

The Mouse river, whose fall for the sixty miles of valley between Minot and Towner (through which the river meanders so as perhaps to double the total distance) is only eighty feet, is also extremely sluggish. Thus even in the unprecedented flood of April, 1904, when the stream was out of its banks and covering the whole valley bottom, it flowed away so slowly that for thirty days at Minot it was within three feet of its highest mark.

The Little Muddy, a stream flowing into the Missouri from the north at Williston, exhibits similar features, though its fall is greater.

On the other hand, the streams in the southwestern portion of the state west of the Missouri, such as the Little Missouri, Cannon Ball, Knife, and Heart, have a larger fall, from three to six feet per mile of valley in the lower portions and much more near the headwaters. This is why they have been able to erode their valleys rapidly and deeply so that cut-banks and bad lands abound. Nor are there forests anywhere in their drainage basins to retard the run-off; in the summer after a rainstorm the water runs violently down the stream, causing a sudden flood, and the stream as quickly returns to its former low stage.

This is markedly shown in the run-off tables of these streams and even more clearly in the diagrams by the great difference between maximum and minimum flow. One of these streams may run ten, twenty, or even 100 times as much water tomorrow as today.

No records of the Missouri river in this state have yet been maintained long enough for publication. This river from the point of view of physiography is a complex problem. Part of its volume comes from the draws, coulees and rivers of the North Dakota prairies with their violent floods at the time of the spring thaw; this causes the spring rise, which then sometimes rises to an abnormal and disproportionate height as a result of ice jams and gorges. Later in the season the snows in the mountain ranges at the headwaters of the Missouri melt, keeping the river at a high-water stage in early summer.

Another point to be noted is that a single year's record gi very inadequate idea of the future behavior of a stream. run-off is ultimately (though some of it is delayed by soa into the earth and thence out from springs) the residual from a variable rainfall after plant absorption, evaporation, all losses have taken place. For the streams of southwes North Dakota the total amount thus unused and running off ı not amount to as much as *one inch* over the whole drainage ba in the course of a year. A very slight difference in the amoı or in the seasonal distribution of the rainfall may cause a diff ence in this residual (the run-off) that is large in comparis with the total amount, and this difference cannot be easily pı dicted.

A thorough understanding of the behavior of even a sing one of our many rivers can not be obtained without a thoroug study of its whole drainage area, including the topography, th grades, the forests or vegetation, the nature and condition of th soil and surface, and the geological structure, followed by a com parison between the region's rainfall and run-off records for many years. But the pages above are a preliminary contribution to the study of the subject.

Many illustrations of the apparent inconsistencies in the behavior of the different streams may be seen in the tables following. For example, in the summer and early fall months of 1904 the average flow of the Red River at Fargo was slightly more than double its average flow for the same month in 1903; the Sheyenne for those months had double the flow of the same months in 1903; the Red Lake River, one and one-halt times as much; the Pembina, more than ten times as much; but the Mouse River averaged less flow than for the same months of 1903; the Knife River less, and the little Missouri less than one-third. These apparent inconsistencies could be explained, at least in part, if space permitted here, but at first glance are surprising.

TABLES SHOWING DISCHARGE IN SECOND-FEET OF NORTH DAKOTA RIVERS

These tables were prepared from a series of daily observations, made under the direction of the U. S. Geological Survey, at each point, and give with reasonable accuracy the quantity of water flowing by the station, maximum flow, minimum flow, and mean

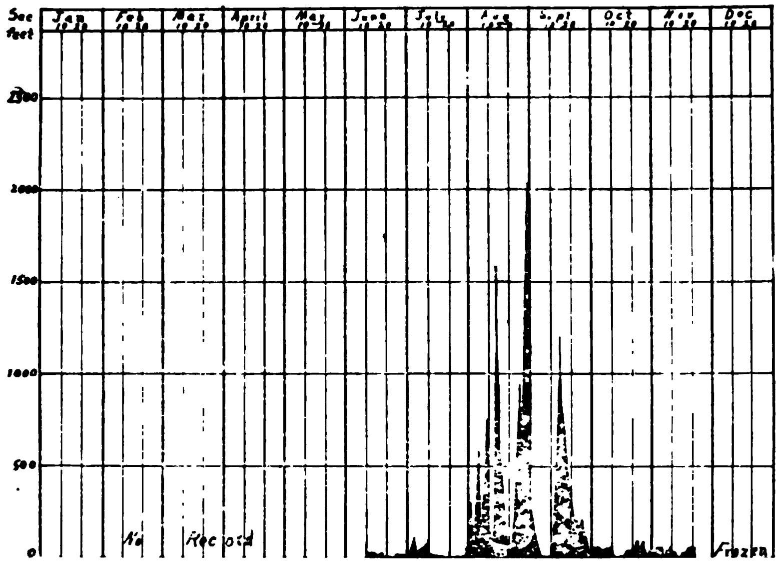

Fig. 1. Discharge of Cannon Ball river at Stevenson, 1903

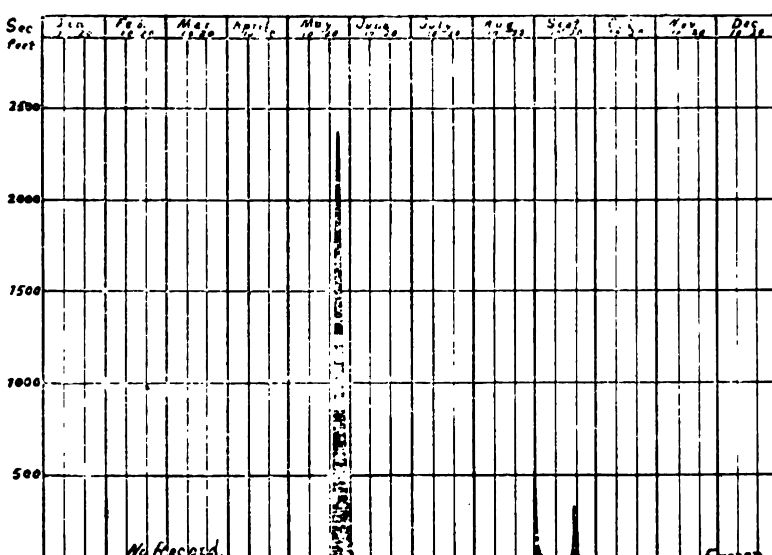

Fig. 2. Discharge of Heart river near Richardton, 1903

or average flow being given. The term "second-feet" is an abbreviation for "cubic feet per second"; it is the number of cubic feet of water flowing by the gauging-station each second. From the number of second-feet of mean discharge by multiplying by the number of seconds in a day or in a month, the total number of cubic feet of water passing down the river in a day or in a month is of course readily found.

RED RIVER AT GRAND FORKS, N. D.

BELOW MOUTH OF RED LAKE RIVER.

(Drainage area about 25,800 square miles.)

Month	Discharge in second-feet		
	Max.	Min.	Mean
1903			
April	18,800	5,900	10,700
May	7,140	4,270	5,390
June	5,870	1,940	3,340
July	2,100	1,060	1,440
August	1,270	870	1,050
September	2,660	1,180	1,890
October	3,940	1,400	2,990
November	......	......	2,200
1904			
April	32,900	2,900	22,200
May	30,200	6,390	14,000
June	6,750	5,070	6,000
July	6,270	2,400	3,920
August	2,280	1,320	1,760
September	1,910	1,460	1,610
October	2,140	1,580	1,850

RED LAKE RIVER AT CROOKSTON, MINN.

(Drainage area about 5,500 square miles.)

Month	Discharge in second-feet		
	Max.	Min.	Mean
1903			
June	2,940	1,060	1,820
July	1,350	810	1,000
August	1,110	450	669
September	2,390	840	1,390
October	2.430	730	1,930
November	1,810	430	1,270
1904			
April 3-30	13,600	2,900	7,810
May	7,620	3,700	4,450
June	3,780	2,940	3,340
July	2,640	1,090	1,820
August	1,290	710	930
September	1,450	760	1,020
October	1,180	760	1,030

PEMBINA RIVER AT NECHE, N. D.

ABOUT 15 MILES ABOVE MOUTH.

(Drainage area about 2,800 square miles.)

Month	Discharge in second-feet.		
	Max.	Min.	Mean
1903			
May	230	167	209
June	198	110	144
July	110	35	60
August	......	......	33*
September	......	......	33*
October	45	32	40
1904			
April 4-30	3.580	30	1,630
May	3,870	1,340	2,640
June	2,530	929	1,620
July	2,690	376	837
August	420	310	383
September	310	225	294
October	266	206	211

*Estimated.

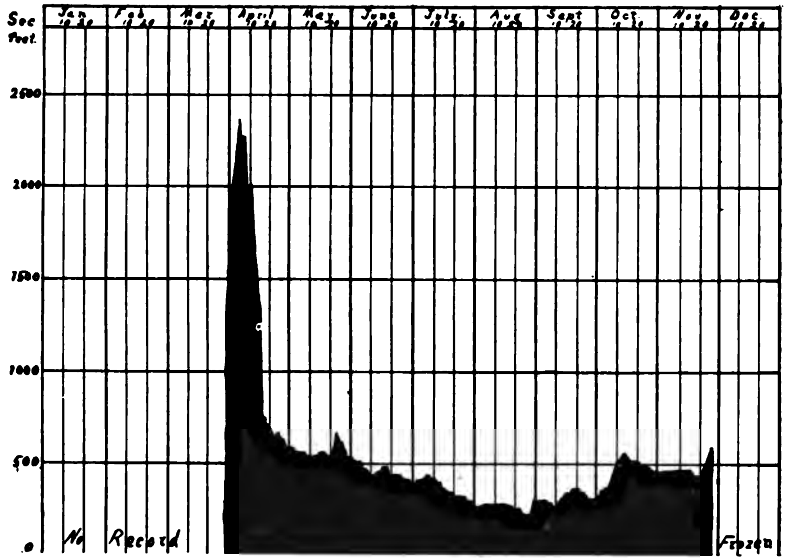

Fig. 1. Discharge of Red River of the North at Fargo, 1903

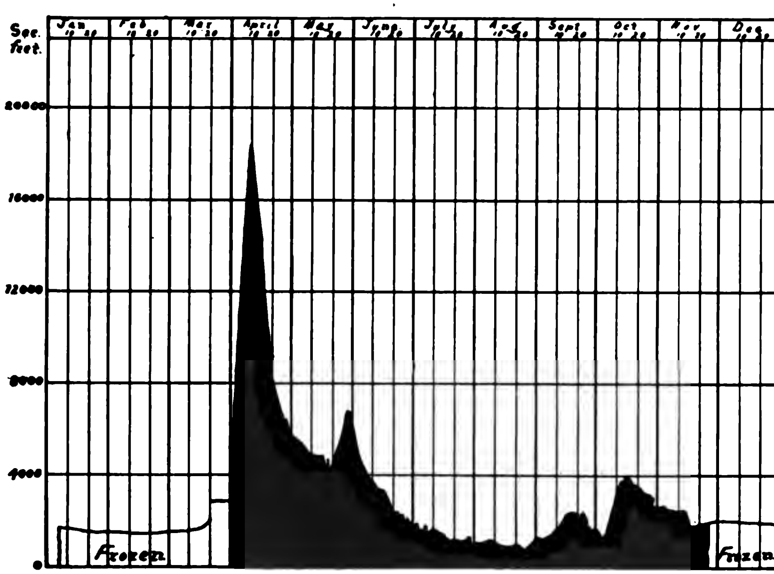

Fig. 2. Discharge of Red River of the North at Grand Forks, 1903

RED RIVER AT FARGO, N. D.

(Drainage area about 6,000 square miles.)

Month	Discharge in second-feet.		
	Max.	Min.	Mean
1903			
April	2,450	565	1,280
May	645	539	577
June	539	392	460
July	439	283	363
August	325	225	268
September	369	263	317
October	565	325	487
November	......	......	474
1904			
April	5,550	1,020	2,780
May	1,650	878	1,050
June	2,820	822	1,270
July	2,350	636	1,100
August	636	378	502
September	512	378	450
October	512	444	483

SHEYENNE RIVER AT FARGO, N. D.

ABOUT 15 MILES ABOVE MOUTH.

(Drainage area about 5,400 square miles.)

Month	Discharge in second-feet.		
	Max.	Min.	Mean
1903			
April 8-30	1,570	410	1,000
May	1,110	158	369
June	302	84	166
July	146	53	80
August	67	20	46
September	113	53	81
October	124	60	99
November 1-14	......	......	100
1904			
April	1,950	810	1,430
May	1,950	368	1,045
June	615	296	418
July	296	139	216
August	130	36	88
September	105	32	83
October	139	80	93

MOUSE RIVER AT MINOT, NORTH DAKOTA.

(Drainage area, 8,400 square miles.)

Month	Discharge in second-feet		
	Max.	Min.	Mean
1903			
May 5-31	347	191	251
June	599	191	324
July	401	178	271
August	248	165	186
September	1,136*	178	696
October	509	205	293
1904			
April 3-30	12,000†	438	5,200
May	7,600	2,080	4,850
June	1,960	402	804
July	402	165	268
August	165	114	128
September	114	60	79
October	87	60	66

*Violent snowstorm early in September.

†Estimated. River out of its banks; highest flood for twenty years.

LITTLE MUDDY RIVER AT WILLISTON, NORTH DAKOTA.

(Drainage area, about 800 square miles.)

Month	Discharge in second-feet		
	Max.	Min.	Mean
1904			
April 3-30	3,000*	750	1,300
May	700	23	164
June	65	16	24
July	16	10	12
August	10	6	8
September	10	6	9
October	10	6	10

*Estimated. Highest flood for years.

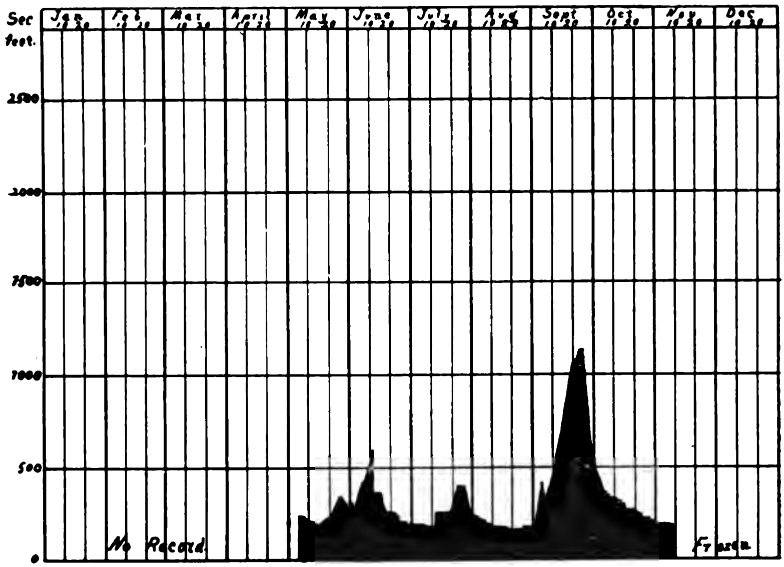

Fig. 1. Discharge of Mouse river at Minot, 1903

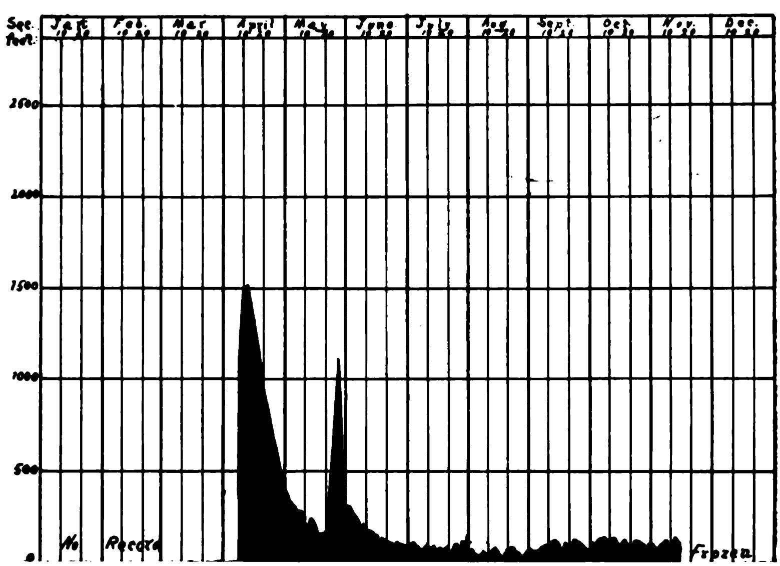

Fig. 2. Discharge of Sheyenne river at Haggart, 1903

CANNON BALL RIVER AT STEVENSON, NORTH DAKOTA,
ABOUT THIRTY MILES ABOVE MOUTH

(Drainage area, about 3,650 square miles.)

Month	Discharge in second-feet		
	Max.	Min.	Mean
1903			
June 10-30	38	7	18
July	116	3	24
August	2,040*	17	434
September	1,270	7	268
October	53	11	38
November 1 21	53	11	40
1904			
April	3,720	195	1,246
May	195	33	95
June	2,040	47	618
July	107	4	31
August	22	0	3
September	8	0	.2
October	107	1	15

*Unusually heavy August rains.

LITTLE MISSOURI RIVER AT MEDORA, NORTH DAKOTA.
ABOUT 140 MILES ABOVE MOUTH.

(Drainage area, about 6,600 square miles.)

Month	Discharge in second-feet		
	Max.	Min.	Mean
1903			
May 12-31	2,880	39	952
June	830	54	237
July	3,900	122	1,083
August	6,100*	500	2,295
September	5,550	176	1,242
October	147	43	68
November 1-14	101	61	76
1904			
March 13-31	2,480	452	986
April	2,480	64	802
May	400	110	180
June	6,090	110	1,195
July	352	27	103
August	27	5	9
September	307	4	80

*Unusually heavy August rains.

HEART RIVER NEAR RICHARDTON, N. D.

ABOUT 100 MILES ABOVE MOUTH.

(Drainage area, 1,270 square miles.)

Month	Discharge in second-feet.		
	Max.	Min.	Mean
1903			
May 18-31	2,500	13	611
June	118	5	22
July	13	0	4
August	530	0	18
September	336	8	67
October	13	8	8
November 1-18	......	.....	8
1904			
April	3,500	151	1,050
May	169	19	56
June	461	13	98
July	13	0	6
August	2	0	1
September	1	0	1
October	4	0	2

KNIFE RIVER AT BRONCHO, N. D.

ABOUT FORTY MILES ABOVE MOUTH.

(Drainage area, 1,250 square miles.)

Month	Discharge in second-feet.		
	Max.	Min.	Mean
1903			
June	64	24	30
July	840	16	60
August	311	16	46
September	217	13	62
October	13	11	12
November 1-14	13	9	11
1904			
April	3,400	111	1,050
May	330	39	97
June	350	26	74
July	39	5	12
August	5	3	4
September	4	3	3
October	14	3	7

A continuous record of the height of the Red river at Grand Forks has been kept since the summer of 1895. By the kindness of Captain John F. Hayes some facts from the record are given here.

Referred to the gauge now maintained by the U. S. Geological Survey, whose zero is 780 feet above sea level, the heights of water at highest and lowest each season with dates, were these:

Year	Highest Water	Lowest Water
1895	....	.........3.8 feet September 26
1896	32.0 feet May 30	.........5.6 feet October 8
1897	50.2 feet April 10*	.........6.9 feet November 13
1898	15.0 feet April 14	.........5.4 feet November 13
1899	20.9 feet April 17	.... .5.7 feet November 11
1900	16.5 feet October 13†..........	.........3.4 feet July 1
1901	26.2 feet April 6	.. ..6.2 feet September 24
1902	26.0 feet March 30	.........5.9 feet October 23
1903	27.9 feet April 11	.........5.0 feet August 24
1994	40.6 feet April 27	........6.0 feet August 30

*Caused by unusually heavy snow the previous winter.

†Heavy rains in the early fall.

The dates on which navigation opened and on which the river froze over at Grand Forks, and the approximate average height of water for each season as a whole (from opening to closing) were these:

1895; navigation opened about April 16; closed November 1.

1896; navigation opened about April 18; closed November 13; average heighth about ten feet.

1897; navigation opened about April 10; closed November 15; average height about fourteen feet.

1898; navigation opened about April 15; closed November 10; average height about seven feet.

1899; navigation opened about April 19; closed December 3; average height about ten feet.

1900; navigation opened about April 14; closed November 15; average height about twelve feet.

1901; navigation opened about April 9; closed November 6; average height about eleven feet.

1902; navigation opened about April 7; closed November 12; average height about eleven feet.

1903; navigation opened about April 13; closed November 14; average height about ten feet.

1904; navigation opened about April 18; closed November 28; average height about twelve feet.

The zero of the gauge on the Red river at Fargo is 861 feet above sea level, and since its establishment the records of highest and lowest water and approximate average during open season are as follows:

1901, highest, —— lowest, 6.8 feet November 6; average height about 8 feet.

1902, highest, 10.3 March 18; lowest 6.7 November 13; average height about 8 feet.

1903, highest, 13.9 April 6; lowest 7.0 August 28; average height about 8 feet.

1904, highest, 21.3 April 20; lowest 7.7 September 1; average height about 10 feet.

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